An Ecological Survey of the Sentinel Meadow Candidate Research Natural Area on the Inyo National Forest, California

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Item 3 Order No. 896-PSW-75

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January 4, 1978

INTRODUCTION

Sentinel Meadow candidate Research Natural Area comprises six sections (1,554 ha) along a ridge forming part of the north rim of the Long Valley Caldra. This area is mid-way between Bald Mountain and Glass Mountain in Inyo National Forest (between 37° 46' to 37° 47' 40" N latitude and 118° 45' 15" and 118° 48' 30" W longitude) and will subsequently be referred to as Sentinel Ridge. Prominent topographic features of Sentinel Ridge included within the proposed natural area are steep (40% and greater) north and south aspects comprising 370 and 552 ha, respectively, and a 447 ha gently sloping plateau ranging between 2,896 m elevation in the west to 3,100 m elevation at the highest point in the eastern third of the study area. Another 184 ha of gently sloping terrain at the northern base of Sentinel Ridge is also within the proposed natural area (Figure 1).

South slopes are underlain by granite and extend between 2,300 m and 2,925 m elevation and, locally, up to 3,050 m elevation (Strand, 1967). Vertical gradients of 473 m per airline kilometer are common. Characteristic south slope vegetation is Jeffrey pine forest or open stands of limber pine, the latter being restricted to exposed southwest to southeast slopes above 2,925 m elevation. North facing slopes are neither as steep nor extensive as south slopes, extending from 2,800 m up to 3,050 m with topographic gradients averaging 400 m per airline kilometer. Slopes of canyons penetrating the north face of Sentinel Ridge may exceed the angle of repose. Parent material

is ryholite with local obsidian outcrops (Strand, 1967). Vegetation on level terrain is typically an open stand of lodgepole pine while north slopes possess lodgepole pine - whitebark pine forests. Greatest diversity in vegetation cover occurs along the crest of the south slope, where, in the western half of the proposed natural area, sagebrush scrub and mountain mahogany woodland occur between Jeffrey pine and lodgepole pine forests about the 2,865 m (9,400 ft) contour line. Along the crest of the south slope in the eastern half of the study area squaw currant thickets (Ribes cereum) and an open subalpine forest occur between limber pine forest and lodgepole pine - whitebark pine forest about the 3,050 m (10,000 ft) contour line (Figure 1). South slopes below 2,440 m usually possess pinyon - juniper woodland.

A prominent floristic feature of the proposed natural area is the presence of species suggesting a relatively mesic climate for a 3,000 m elevation ridge just east of the Sierra Nevada: Pinus monticola, P. albicaulis, and Chrysolepis sempervirens.

This study will provide a general ecological description of vegetation within the proposed Sentinel Meadow Research Natural Area giving particular emphasis to composition, growth, and structure of montane and subalpine coniferous forests.

METHODS

Vegetation was field mapped according to dominant species and results transcribed onto an enlarged 15 min series topographic sheet for Cowtrack Mountain, California. Sites believed representative of forest vegetation within this region were

subsequently analysed using 75 X 100 ft (0.07 ha) plots with the long axis parallel to the slope direction (see Figure 1 for plot distribution). Arboreal species 5 cm dbh or greater were evaluated using count-plot methods (cover percent, density, and basal area) to produce an importance value (Curtis and McIntosh, 1951). A preliminary floristic list for the region (DeDecker, unpublished) is included as an appendix and assessed to provide a preliminary view of communities within the study area.

Growth of conifers was evaluated using site index (Avery, 1967) based on height or diameter at breast height (1.4 m). Growth rates were also obtained for a limited number of conifers less than 5 cm dbh by cutting and aging stems at 2.25 ft (68.6 cm)intervals. Height of trees over 3 m tall was determined with a slope corrected Spiegal Relaskop. Age-diameter and sapling age-height data were used to derive 50 year age-size classes for Pinus jeffreyi, P. contorta, P. flexilis, and P. albicaulis. Log-densities per age class were then computed for these trees revealing trends in establishment and/or survival over the past five centuries.

Landscape factors (slope, aspect, and elevation) were recorded for each study site, and were used to assess potential solar beam irradiation (Frank and Lee, 1966) for representative examples of forest and scrub cover types.

CLIMATE

Climatic records are not available for Sentinel Ridge. Examination of vegetation cover (Figure 1) indicates this area is more xeric than the east slope of the Sierra Nevada about

Mammoth Mountain, but decidedly more mesic than Glass Mountain to the east. Precipitation is between 66 cm/yr (Gem Lake on the east slope of the Sierra Nevada 28 km west of the study area) and 15 cm/yr (the average for Bishop in the Owens Valley 48 km southeast of the study area) (U.S. Dept. of Agriculture, 1955). The only climatic record for a region of similar elevation and distance east of the Sierra Nevada crest is the ghost town of Bodie for which an 11 year record (1895-1906) exists. Bodie lies at 2,512 m elevation and is approximately 42 km north of the study area. Vegetation is sagebrush scrub and therefore more xeric than the dry lodgepole pine forest and Jeffrey pine forests on Sentinel Ridge. Nevertheless, average precipitation at Bodie is nearly 37 cm/yr with 2.5 cm/month or more falling from November through May. June is the driest month (0.71 cm) with July through October receiving 1.3 to 1.9 cm/month (U.S. Dept. of Agriculture, 1955). Using these data as a base, an estimate of Sentinel Ridge precipitation would be 45 to 55 cm/year with a slightly greater percentage of the total falling during the period November through April. (The gap in the Sierra Nevada at Mammoth Mountain would give the Sentinel Ridge greater access to strongly seasonal polar front cyclones, the major source of precipitation in central California).

Temperature variation on Sentinel Ridge is high. During the course of this study calm-hot (35° C) summer days were encountered often to be followed by cold windy days. Between November and the end of March, midday temperatures just above freezing appeared to be normal. Nighttime temperatures below 0° C were normal except for summer, but could occur in any month.

(I recorded -4° C at dawn in August 1975.) These observations suggest a temperature record similar to that of Bodie about the turn of the century (Table 1).

Development of a winter snow pack was not observed between 1975 and 1977. However, in a normal or above normal precipitation year significant snow accumulation should occur on north slopes and level areas where the ground is shaded by trees. Evidence for this observation stems from two separate November snow storms which deposited approximately 10 cm of powder on the study area. On north slopes the snow remained as powder for over a week, while it had melted within five days on the south facing slope of Sentinel Ridge.

RESULTS

Vegetation

Thirty-three sites were examined representing nearly all slope, aspect and elevation combinations within the Sentinel Ridge study area (Table 2). Two scrub and five forest cover types were encountered within the proposed natural area. In order of the following discussion these cover types are: sagebrush scrub, mountain mahogany woodland, subalpine forest, Jeffrey pine forest, lodgepole pine forest, lodgepole pine-whitebark pine forest, and limber pine forest.

Sagebrush scrub

Sagebrush scrub occurs over 64 ha of even-grading south to southeast aspect, principally about the 2,926 m (9,600 ft) contour interval along the ridge crest ecotone between Jeffrey pine forest and lodgepole pine forest (At in Figure 1). Sagebrush

scrub appears relatively undistrubed, probably due to the remoteness of these sites from surface water and the difficulty range cattle would experience traveling across the loose rhyolite soils and/or steep slopes of adjacent vegetation types.

Vegetation cover is about 50%, one fifth to half of which is Artemisia tridentata. Many additional sagebrush scrub species are those which are also found throughout montane and subalpine forest and scrub cover types of this region: Symphoricarpos vaccinoides, Monardella odoratissima ssp. parviflora, Haplopappus suffruticosus, Leptodactylon pungens, Holodiscus microphyllus, Purshia tridentata, Ribes cereum, Eriogonum umbellatum var umbellatum, Sitanion hystrix, and Stipa elmeri (Table 3). Other species like Orobanche corymbosa, Tetradymia canescens, Silene montana ssp. bernardina, Oryzopsis hymenoides, and Stephanomeria tenuifolia are more or less restricted to the sagebrush scrub cover type and mountain mahogany woodland discussed below.

Mountain Mahogany Woodland: Thirty-six hectares of the Sentinel Ridge study area are classified as mountain mahogany woodland (C1 in Figure 1). Like the sagebrush scrub, mountain mahogany woodland is concentrated along the upper margin of the Jeffrey pine forest where an ecotone forms with lodgepole pine or limber pine cover types. Unlike sagebrush scrub, mountain mahogany woodland is restricted to windy sites below 3,000 m elevation with steep convex south exposure and rocky soil. Cercocarpus ledifolius is the principal dominant accounting for at least 700 stems/hectare but less than 20% cover and 10 m^2/ha basal area (see plot 7; Table 4). With the possible exception

of Abronia turbinata and Lygodesmia spinosa, associated species within mountain mahogany woodland appear to be identical to the sagebrush scrub (Table 3).

Subalpine Forest: Fifty-four hectares above 2,990 m elevation on the southern half of the plateau area are characterized by gently undulating topography with loose rhyolite soil and local obsidian outcrops. Vegetation of this region consists of clusters of Pinus albicaulis, P. flexilis, and P. contorta (SC in Figure 1). Total arboreal cover is less than 1% and varying degrees of slope exposure and wind action have produced three more or less distinguishable types of herb stratum habitat: areas exposed to very strong south winds which remove fine soil particles producing a rock or pebble pavement, regions of local removal and/or deposition of fine to coarse sand particles, and areas of significant deposition of wind blown soil.

Regions along the southern and eastern rim of the 3,000 m elevation plateau have a stony soil pavement due to wind removal of finer soil particles. They are characterized by isolated clusters of pines, usually P. flexilis, and sparse (5-15%) herb and shrub stratum cover of Chrysothamnus viscidiflorus ssp. viscidiflorus, Haplopappus macronema, Leptodactylon pungens ssp. hallii, Phlox covillei, Eriogonum ovalifolium var. nivale, Eriophyllum lanatum var. monoense, Holodiscus microphyllus, Lupinus breweri, and occasional Cercocarpus ledifolius (Table 3).

Areas of alternative removal and deposition of sandy soil comprise well over half of the subalpine forest. Vegetation is an open patchwork of Ribes cereum thickets between which

cover is very sparse (5% or less). Open areas between Ribes thickets possess the same species which occur at plateau rim sites as well as other species which may occur only here: Hulsea vestita, Raillardella argentea, Senecio spartioides, Cryptantha confertiflora, Lupinus montigenus, and Mimulus coccineus (Table 3). Well developed clusters of Ribes cereum comprise about 5% of the subalpine scree. They form an effective barrier to wind blown sand particles and may build the soil to nearly a meter above the original level. During winter these same thickets trap significant quantities of wind blown snow. Few other plants occur in Ribes thickets although they may provide significant cover for small game.

Vegetation cover is nearly absent in areas of significant sand deposition within the subalpine forest. These areas occur primarily in depressions left by two volcanic caldras, and vegetation consists almost entirely of widely spaced specimens of Lupinus breweri.

Jeffrey Pine Forest: Three hundred and forty-nine hectares of south exposure within the study area is vegetated with Jeffrey pine forest (PJ in Figure 1). Soil is a coarse friable granite with slopes at or near the angle of repose. Stocking within Pinus jeffreyi forests is relatively uniform (124 ± 64 stems/ha) accounting for 41 ± 13 m^2/ha basal area and 43 ± 12% cover (see plots 36 and 5 in Table 4). Jeffrey pine is the sole dominant at most sites, although Juniperus occidentalis ssp. australis may be also abundant on convex slopes of lateral ridges (Plot 36) and about the 2,450 m contour line. Cercocarpus ledifolius is

also common within Jeffrey pine forest where terrain is rocky and exposed and slopes convex (e.g. plot 5, Table 4).

All mature Pinus jeffreyi are flat-topped and nearly all intermediate sized specimens possess crooked trunks due to top loss and subsequent regrowth. Evidence of this same phenomenon is also apparent on trunks of the largest trees. Jeffrey pine often occur as two or more trunks which are grown together at the base. Observation of germinating seed in 1975 revealed that this is probably the result of seed dropping out of cones after they fall.

About the 3,000 m contour line an ecotone forms between Jeffrey pine and limber pine forest (plot 32). Pinus jeffreyi growing at these sites are often stunted after many years growth, seldom developing cones and probably never producing viable seed (e.g. number 16). Conversely, Pinus jeffreyi invading sagebrush scrub (plots 34 and 43) are vigorous and bear abundant cones although successful seedling establishment appears to be rare.

Common associates within Jeffrey pine forest are shared with the sagebrush scrub and mountain mahogany woodland cover types: Artemisia tridentata, Castilleja martinii, Cercocarpus ledifolius, Chrysothamnus nauseosus, Eriogonum umbellatum var. umbellatum, Eriophyllum lanatum var. monoense, Gayophytum diffusum ssp. parviflorum, Holodiscus microphyllus, Lygodesmia spinosa, Purshia tridentata, Silene bernardina ssp. maguirei, Stephonomeria tenuifolia, Symphoricarpos vaccinoides, and Sitanion hystrix (Table 3). Chrysolepis sempervirens is restricted to the Jeffrey pine forest while Streptanthus

tortuosus, Cryptantha muricata var. dentata, and Eriogonum spergulinum var. reddingianum are largely restricted to this cover type (Table 3).

Lodgepole Pine Forest: Pure or nearly pure stands of Pinus contorta ssp. murrayana cover 770 ha or 50% of the proposed natural area (PC in Figure 1). Lodgepole pine occur on level or gently sloping terrain about the east, north and western flanks of Sentinel Ridge and on the western and northeastern slopes of the Sentinel Ridge plateau (Plots 10 through 1 in Table 4). (Mixed Pinus contorta - P. albicaulis stands occurring ng on the north slope of Sentinel Ridge and above 3,000 m elevations on the western, northern, and eastern slopes of the plateau rim will be discussed in the next section.) Essentially pure lodgepole pine forests on gentle western slopes of the Sentinel Ridge plateau (Plots 3,9, and 20) and level to gently sloping terrain north and east of Sentinel Ridge (Plots 1 and 17) combine relatively high shrub and tree stratum cover and basal area (43 ± 8% and 29 ± 9 m^2/ha, respectively). Frequency of P. contorta within these forests is 240 ± 145 stems/ha (Table 4).

Frequency, cover and basal area of Pinus contorta stands declines with increasing elevation and exposure on the Sentinel Ridge plateau. Lodgepole pine forests on gentle terrain above 3,000 m elevation are usually open stands with larger individual specimens representing only four or five size classes (Plots 12, 21, 22). Where upper plateau Pinus contorta are exposed to strong south winds stands are composed of only a few trees with reduced, wind-trained branches but significant girth (Plots 10 and 27, Table 4).

Common understory species within lodgepole pine forest are Carex sp., Gayophytum nuttallii, Sitanion hystrix, Stipa elmeri, Poa nervosa, Ribes cereum, R. roezlii, Symphoricarpos vaccinifolia, Lupinus breweri and L. alpestris . Species which may be confined to the lodgepole pine forest on Sentinel Ridge include Chaenactis douglasii, Frasera puberulenta, and Pterospora andromedea (Table 3). Scrubby Populus tremuloides are found in lodgepole pine forest on gentle slopes about the northern edge of the study area (e.g. plot 1). Total herb stratum cover seldom exceeds 25%, probably due to the xeric environment created by the coarse rhyolite soil which permits surface drainage only during occasional periods of maximum precipitation.

Lodgepole Pine - Whitebark Pine Forest: Mixed stands of Pinus contorta and P. albicaulis cover 287 ha and are almost exclusively restricted to north facing slopes of Sentinel Ridge (Pc-Pa and Pa-Pc in Figure 1). Additionally Pinus contorta - Pinus albicaulis forests on steep northwest to northeast aspects of two large canyons cutting into Sentinel Ridge's north slope possess occasional Pinus monticola (X's in Figure 1).

Within north slope forests Pinus albicaulis and P. contorta have approximately equal frequency and percent cover (292 ± 230 versus 218 ± 173 stems/ha and 12 ± 8 versus 16 ± 11% cover, respectively). Layering and subsequent formation of clusters of many stems in Pinus albicaulis occasionally produces local areas with basal area exceeding 200 m^2/ha (e.g. plot 22). However, the average basal area of whitebark pine at the six other sites examined was only 7.8 m^2/ha - about one-third the basal area of lodgepole pine (Table 4). Widely spaced Pinus

monticola within north slope canyons accounted for approximately 30 stems/ha, 5% cover and 6 m^2/ha basal area (Plot 29). Damaged crowns and partially rotten trunks were common within P. monticola.

Relative to plateau lodgepole pine forest, Pinus contorta growing within lodgepole pine - whitebark pine forests are small. Smaller stature of north slope Pinus contorta and formation of stem clusters in P. albicaulis explain why north slope forests have over twice the total number of stems per hectare but equivalent cover as plateau forests (481 ± 244 versus 204 ± 137 stems/ha and 29 ± 10 versus 36 ± 13 % cover, respectively).

Understory species occurring within north slope forests are the more cold-tolerant members of the plateau lodgepole pine forest: Arabis holboellii, A. invoensis, A. platysperma, Calyptridium umbellatum var. caudiciferum, Carex sp., Erysimum argillosum, Lupinus alpestris, Poa nervosa, Stipa elmeri and others (Table 3). Eriogonum lobbii and Arabis holboellii appear to be largely confined to north slope forests - with the former especially common on obsidian outcrops.

Limber Pine Forest: Limber pine forest extends over 205 ha, nearly all of which occurs on south and east exposures between 2,084 and 3,048 m (9,200 and 10,000 ft) elevation in the eastern half of the study area (Pf, Pf-Pc and Pf-Pj in Figure 1). Very open stands (10 to 15% tree cover) are typical of sites with significant elevation and strong southwest to southeast slope exposure (Plots 17 and 18, Table 4). Limber pine forest with south aspect and below 2,900 m elevation may also possess

wind distorted specimens of Pinus jeffreyii (Plots 15 and 16). Less steep slopes about the plateau rim or exposed sites with northwest to northeast exposure result in mixed stands of Pinus flexilis, P. albicaulis, and P. contorta (Plots 19,21 and 28 in Table 4).

Percent cover, basal area, and frequency of Pinus flexilis varies widely, but these changes can seldom be attributed to presence or absence of associated trees. For example, plot 28 possesses 5% cover of Pinus contorta but P. flexilis cover is 30% making this site the densest limber pine stand evaluated. Plot 19 possesses 20% cover of Pinus albicaulis but still has 10% cover of limber pine - a cover value equivalent to those at other sites where limber pine, alone, is present. Similar trends hold for basal area (see Table 4). One explanation for these trends is that limber pine forests are establishment limited so there is little direct interaction between mature trees.

Herb and shrub stratum taxa found within limber pine forest consist largely of widespread species: Arabis platysperma, Antennaria rosea, Haplopappus suffruticosus, Monardella odoratissima, Leptodactylon pungens ssp. hallii, Calyptridium umbellatum, although Lesquerella kingii may be confined to this cover type in the Sentinel Meadow area (Table 3). Plot 25 is exceptional for the presence of Chamaebatiaria millefolium.

Growth

Sapling Growth.

Development of sapling Pinus albicaulis, P. contorta, and P. flexilis is slow, with approximately 50 years elapsing between seed germination and the time saplings reach breast height (1.4 m). Sapling Jeffrey pine grow twice as fast, attaining breast height in slightly over 25 years (Table 5).

Tree Diameter Growth.

Mature specimens of Pinus jeffreyi, P. contorta, P. albicaulis, and P. flexilis were encountered in sufficient numbers to permit quantitative estimates of diameter and height growth rates. Early diameter growth of Pinus jeffreyi is high, averaging 6 and 5 mm/yr respectively, over the first and second 50-year intervals after reaching breast height. Subsequent diameter growth is both slower (approximately 3 mm/yr) and more variable (Figure 2). Two of the oldest specimens encountered were estimated to be 500 years old and had dbh's of 139 cm. The sharp over-all reduction and increased variability in Jeffrey pine diameter growth after 100 years derives from wind damage to tree crowns as they grow above approximately 15 m height.

Two types of age-diameter relationships exist for Sentinel Ridge Pinus contorta. Trees growing on level to gently sloping topography increase in diameter rapidly, averaging 4.2 mm/yr during their first 100 years after reaching breast height (representing 150 years total age). Over the 100 to 150 year range growth slows to an average of 3.2 mm/yr and probably assumes near linear growth of 2.9 mm/yr thereafter

(Figure 3). Lodgepole pine on steep terrain also exhibit rapid diameter growth in the first 50 years after attaining breast height, but abruptly enter a linear phase averaging only 1.2 mm/yr for the remainder of their existence (Figure 3). Reasons for distinction in diameter growth rate of lodgepole pine on gently sloping versus steep sites will be discussed.

Age-diameter relationships for Pinus albicaulis cannot be distinguished according to "gently sloping" versus "steep" sites. Rather, there is a nearly linear increase in diameter between 0 and 300 years age at breast height (representing approximately 50 to 350 years total age). Growth during the first 150 years averages 1.4 mm/yr compared to 1.6 mm/yr for the 150 to 300 year interval (Figure 4).

Average diameter growth for 9 Pinus flexilis ranging from 55 to 555 years old at breast height was 2.0 ± 0.5 mm/yr. Growth was nearly linear across this age span (Figure 5).

Tree Height Growth.

Pinus jeffreyi seedlings reach breast height (1.4 m) in about 25 years and are between 10 and 15 meters tall in another 75 years (Figure 6). At 15 meters height crowns of young P. jeffreyi are high enough into the open forest canopy to be subjected to southwest winds which eventually removes the top from every mature tree. Results are trees with flat-topped or bushy crowns and highly variable height growth averaging 2 cm/yr between 100 and 500 years total age! Only young Pinus jeffreyi occur at the species' upper elevational limit in limber pine forest (e.g. plot 16 at 3,024 m elevation). These Jeffrey pine

exhibit wind and/or cold damage at a very early age and rarely exceed 5 m tall at 100 years total age.

Three height growth classes can be recognized within Sentinel Ridge Pinus contorta: Trees growing in gently sloping terrain which are usually sheltered from wind (Height class I), trees growing in upland regions but on slopes providing protection from direct influence of wind (height class II), and trees on the exposed plateau rim or steep canyons sites (height class III). Trees in height classes I and II almost always belong to diameter class I while trees in height class III are in diameter class II (Figure 7).

Height class I Pinus contorta occur on gently sloping terrain of the western half of the plateau (Plots 8, 9, 20) and on lower slopes of wide canyons in the eastern third of the study area (Plot 17). During the first 100 years after reaching breast height growth is rapid, averaging 15.1 cm/yr with trees at 9 and 16.5 m height after 50 and 100 years, respectively. Subsequent growth slows to 8.0 cm/yr (100-150 years at breast height) and approximately 6.0 cm/yr thereafter (Figure 7).

Height class II Pinus contorta are those occurring on sheltered slopes about the plateau rim (Plots 12, 15, 18) at the base of the north slope (Plot 1) or on level terrain where wind exposure is significant (Plots 21, 27). Average growth rate during the first hundred years after reaching breast height is 12.1 cm/yr.

Height class III lodgepole pine are those which grow about the exposed edges of the 3,050 m elevation plateau in the east central half of the study area (Plots 23-25, 27 and 28) and in steep rocky ravines with north exposure (Plot 29). Height class III trees grow rapidly during their first 50 years above breast height - averaging 13 cm/yr and become approximately 8 meters tall. However, average yearly height growth falls to 8 cm/yr between 50 and 100 years, 5 cm/yr between 100 and 150 yrs, and only 3.5 cm/yr for the 150 to 200 year interval. After 200 years continued height growth with age is too variable to evaluate quantitatively (Figure 7).

Early height growth of Pinus albicaulis is low, probably averaging little more than 3 cm/yr throughout the first century after reaching breast height, after which trees are only 4.5 m tall. During the next 100 years growth of whitebark pine at sites not receiving direct exposure to strong winds (Plots 15, 18, 23, 24, and 29) accelerates to 8.5 cm/yr. Subsequent height growth returns to approximately 3 cm/yr (Figure 7). Tops of trees older than 200 years are usually wind damaged, consisting of a dozen or more decurrent branches. Where whitebark pine grow in the presence of strong winds, as along promontories about the eastern half of the Sentinel plateau (Plots 14 and 25), height growth may be no greater than 3 cm/yr for over three centuries (Figure 7).

Height growth of Pinus flexilis is low, averaging 4.5 and 3.5 cm/yr, respectively, during the first and second centuries

after reaching breast height. Repeated wind damage to the crowns nullifies height growth with age after 200 years at breast height (Figure 8).

Structure

Combined assessment of age of saplings at breast height (Table 5) and age-diameter relationships of trees after they reach breast height (Figure 2 through 5), permit the derivation of approximate 50 year age-size classes for each conifer species studied except Pinus jeffreyi (Table 6). High variability in age-diameter relationships for old Jeffrey pine (Figure 2) resulted in derivation of age-diameter relationships for this species on a plot-by-plot basis. Subsequent examination of log frequencies per size class within each species provides for a structural assessment revealing deviations from uniform establishment and/or mortality over time.

Gap-phase reproduction and establishment is a conspicuous feature of Pinus jeffreyi stands which can be divided into four or five size classes by visual inspection. Quantitative analysis of stand structure reveals four definite peaks in successful establishment separated by broad gaps during which no successful establishment occurred (Figure 9). Jeffrey pine belonging to the peak consisting of age classes 1 and 2 (1875 to 1975) account for 55% of the stand and result from at least four separate periods of successful establishment: 1895-1905, 1915-1925, 1925-1935, 1945-1955. Subdivision of establishment in age classes 5,6,8, and 10 within the 50 year age class is not technically feasible. Stands on the southwest flank of

Sentinel Ridge (Plots 4, 6, 7, 38, 39, 44) are largely composed of age class 5, 6, and 8 trees, while stands on the southeast flank are strongly represented by age class 1 and 2 trees. Reasons for the broad spacing between periods of successful establishment and differences between Pinus jeffreyi stands on the western versus eastern ends of Sentinel Ridge will be discussed.

Pinus contorta age classes 6 through 2, representing 1625 to 1925,are characterized by more or less constant establishment resulting in a negative log linear frequency per age class distribution (Figure 10). Deficiencies in Pinus contorta establishment and/or survival occurred in age classes 7 and 9 (1625-1675 and 1525-1575, respectively), while abnormally large numbers of trees are attributable to age class 8 (1575-1625) and possibly age class 10 (1475-1525).

Within this forest significant differences in structure are found between protected plateau, exposed plateau, and north slope sites. Nearly pure lodgepole pine forests on gently sloping protected sites at the west or east ends of the study area (Plots 8, 9, 17, and 20) exhibit a strong negative log-linear frequency-per-size-class distribution (Figure 10). Mortality within this forest of rapidly growing trees is high with few specimens exceeding 350 years old.

Lodgepole pine forests on exposed plateau sites, those above about 3,000 meters elevation or at the base of the north slope of Sentinel Ridge, exhibit a strong gap-phase age class distribution. Pinus contorta from age classes 8 (1575-1625) and 4 (1775-1825) are abundant while a definite gap

exists for age classes 7 and 6 (1625-1725). Establishment between 1825 and 1925 was also significant but far below the "peak" establishment period of 1775 to 1825 (Figure 11).

Numerous Pinus contorta within north slope lodgepole pine - whitebark pine forests live into the 400 to 500 year range. The age class distribution of Pinus contorta within these north slope stands is strongly gap-phase, almost cyclic, with above average representation from classes 10, 8, 6, and 2 and below average representation for age classes 3, 5, 7, and 9(Figure 11). Peaks for numbers of specimens in age classes 8 (1575-1625) and 2 (1875-1925) and the gap for age class 7 (1625-1675) are especially large.

Seedling Pinus flexilis may germinate in very close proximity to one another, ultimately producing clusters of stems in direct competition for a small site (Woodmansee, 1977). Stems of resultant clusters may be of very different size but are usually the same age. Since our objective is to determine periods of successful establishment the age of stems at each cluster was determined by coring the largest trunk for each cluster and applying this value to the remaining stems. This procedure reveals limber pine establishment occurred between 1525 and 1575 (age class 9), 1625 and 1825 (age classes 7 through 3), and between 1925 and 1975 (age class 1). Gaps in limber pine establishment occurred from a least 1575 to 1625 and again between 1875 and 1925 (Figure 12).

Layering in Pinus albicaulis results in clusters of stems with variable ages. Once established a stem cluster may

persist long after the original trunk or group of trunks has decomposed. Age class distribution of Pinus albicaulis may, thus, bear little in common with periods of establishment. However, evaluation of the largest stem within each whitebark pine cluster might represent actual age of establishment for some clusters. These latter data suggest nearly uniform establishment between 50 and 600 years ago except for age classes 8 and 9 (1525-1625). Size class 1 stems could not be evaluated as it is impossible to determine which layered branches will form vertical shoots at a later date.

Fire

Dates of fires were estimated by coring trees with fire scars and removing and aging small sections of old fire scars which were too decayed to core. Data are not sufficient for quantitative evaluation but suggest numerous fires have entered the Jeffrey pine forest where it abuts sagebrush scrub or pinyon - juniper woodland between 1800 and the beginning of the 20th Century (Plot 39, Table 7). However, only the earliest recorded fires, 1800 and 1858, burned any distance into the Pinus jeffrevi forest (Plots 37 and 44). The only regional fire within lodgepole pine forest appears to be the 1800 burn (Plots 27 and 40). Fires during 1845 and 1864 appear to be local and may have burned only a few hectares apiece.

Potential Solar Beam Irradiation and the Distribution of Vegetation Cover Types

Potential solar beam irradiation (PSBR) is a theoretical parameter reflecting the intensity of solar irradiation a surface would receive if factors which vary from day to day (clouds, smog, dust, atmospheric moisture) are omitted. Although PSBR usually differs appreciably from actual irradiation at a given site, it provides a rapid and meaningful method for comparing energy flux of different landscapes (Frank and Lee, 1966). Potential solar beam irradiation is used here to compare the "typical" slope-aspect conditions (derived from Figure 1) for the various forest and scrub cover types which occur within the Sentinel Meadow study area (Table 8).

The greatest PSBR (294 - 316 x 10^3 ly/yr) occurs on the steep south facing slope of Sentinel Ridge where Jeffrey pine, limber pine, and mountain mahogany woodland cover types predominate. All of these cover types are characterized by a minimum (Dec 22) PSBR above 500 ly/day. Maximum PSBR, however, is under 1,000 ly/day and may occur during either spring or summer (Table 8). Cercocarpus ledifolius, the dominant of mountain mahogany woodland, is found at sites with the highest potential solar energy inputs (those with total PSBR above 300 x 10^3 ly/yr and minimum PSBR above 600 ly/day). Jeffrey pine occurs in areas with slightly lower winter insolation (Dec 22 PSBR exceeds 500 ly/day) where total PSBR ranges between 290 x 10^3 and 320 x 10^3 ly/yr. When maximum summer PSBR exceeds

1,000 ly/day and minimum PSBR falls below 500 ly/day Pinus jeffreyi establishment becomes limited and sagebrush scrub predominates. Limber pine forests appear to have PSBR regimes which are similar to Jeffrey pine forest. However, Pinus flexilis also occurs as a very sparse cover on colder west and east facing slopes which are very steep and on partially decomposed obsidian substrate. Here total PSBR may fall as low as 200 x 10^3 ly/yr with minimum PSBR in the 200 ly/day range.

Pure or nearly pure lodgepole pine forests occur on gentle slopes of west, north, or east aspects. These conditions result in less total but greater seasonal range in PSBR than occurs on the steep south slope or the southeastern crest of Sentinel Ridge. Maximum daily PSBR occurs on June 22 and exceeds 1,000 ly/day, while the minimum (Dec 22) value seldom exceeds 300 ly/day (Table 8). Pinus contorta can tolerate sites with much lower insolation potential than outlined above (as the steep north face of Sentinel Ridge) but growth rates are lower. When slopes are sufficiently steep to reduce total PSBR to the 200 x 10^3 ly/yr range with a mid-winter PSBR of approximately 100 ly/day, Pinus albicaulis and , locally, P. monticola form mixed stands with lodgepole pine.

DISCUSSION

The sagebrush scrub occupies a narrow band about the 2,960 m contour line along the ridge crest ecotone between south slope Jeffrey pine and plateau lodgepole pine forests. Three types of evidence suggest the existence of sagebrush scrub on Sentinel Ridge derives from a gap between the tolerances for establishment

of Pinus jeffreyi and P. contorta. First, the maximum (spring or summer) PSBR associated with Pinus jeffreyi forest is below the maximum PSBR attained within the sagebrush scrub while the minimum (Dec 22) sagebrush scrub PSBR exceeds values estimated for P. contorta on gentle topography. Second, individual P. jeffreyi and P. contorta seedlings which do become established within sagebrush scrub date from periods of exceptional moisture. Once established they grow rapidly and produce sound seed. (If insolation-induced desiccation of pine seedlings alone was preventing forest encroachment into the sagebrush scrub, we would expect occasional trees which become established during periods of atypically moist climate to thrive). Third, sagebrush scrub species form extensive ecotones with and predominate within local clearings in both Jeffrey pine and lodgepole pine cover types.

Mountain mahogany woodland is well developed only on steep rocky southeast to southwest exposures. While the high annual PSBR and low seasonal variation in daily PSBR calculated for mountain mahogany woodland may represent an energy limitation upon the distribution of this cover type, a more plausible hypothesis is that the distribution of Cercocarpus ledifolius is determined primarily by competition. For instance, Cercocarpus stands below 2,800 m elevation are on sites which are too dry for development of Jeffrey pine forest. Above 2,800 m elevation climate is too cold for development of large Jeffrey pine, and Cercocarpus are more abundant, forming a sparse cover by itself or with limber pine. Observation of the ecotone

between mountain mahogany woodland and sagebrush scrub further reveals Cercocarpus is always on more porous, rocky soils. (Rocky sites provide an uneven distribution of potential rooting space and increase the chances an individual germinating seed will become established at a microsite not currently being tapped by neighboring plant species.)

Sentinel Ridge Jeffrey pine stands are restricted to south facing slopes and are best developed on soils derived from granitic substrate. These soils appear to have superior moisture retention capacity in comparison to soils formed from the decomposition of rhyolite or obsidian which occur over the remainder of the study area. Higher moisture holding capacity of granitic soils may effect the distribution and density of Pinus jeffrevi through enhanced seedling survival.

Steep south facing slopes also modify local climate in ways which are critical for the survival of Jeffrey pine on Sentinel Ridge. High fall, spring, and especially winter solar beam irradiation within Pinus jeffrevi stands reduces both the extent and duration of the snow pack, and may be especially important at stands near the upper altitudinal limit for this species. Conversely, solar beam irradiation during summer is lower than that received by surrounding level terrain, implying a reduction in both temperature and vapor pressure deficit near the soil surface during a time of the year when drought stress becomes critical for seedling establishment.

Despite slope-aspect moderation of regional climate, Pinus jeffrevi on the south flank of Sentinel Ridge are near their limits of tolerance respecting moisture. Nowhere does this

limitation appear to have a more pronounced effect than at seedling establishment. Stands where the largest trees may be up to 500 years old often consist of but four or five age classes, despite the presence of good seed during many years and absence of large-scale removal of either seedlings or saplings by fire or predators. Climatic evidence for moisture stress limiting establishment of Pinus jeffreyi is very strong and will be discussed with stand structure.

The presence of rapidly growing Pinus jeffreyi about springs and seepage areas within the sagebrush scrub and pinyon-juniper woodland at the southern base of Sentinel Ridge provide direct evidence for moisture limitation of this tree at its lower elevation limits along the 2,500 m contour line. Upper elevational limits for Pinus jeffreyi are between 2,800 and 2,900 m where this cover type merges with limber pine and/or mountain mahogany woodland. Pinus jeffreyi at these elevations exhibit numerous symptoms of cold stress: low stature and twisted knarled branches, absence of cones or presence of deformed cones, and brown needles or needle tips on the current season's whorl.

Above the Jeffrey pine forest vegetation on the south slope of Sentinel Ridge is a sparse cover of Pinus flexilis and/or Cercocarpus ledifolius. Close inspection of individual Pinus flexilis suggest this tree is limited by competition to the extent it may be widespread only in regions where physical environment is unsuitable for other Sentinel Ridge dominants. We have already noted cold injury prevents development of Pinus jeffreyi above 2,800 m except as an occasional stunted tree. Moreover, close inspection of "mixed" Cercocarpus

ledifolius - Pinus flexilis stands reveals Cercocarpus exists primarily as open stands on decomposed rhyolite or obsidian talus, while P. flexilis grows on or directly adjacent to rock outcrops between the talus. Juniperus occidentalis ssp australis are occasional throughout south slope limber pine forests but their numbers are too few to be quantitatively important. Pinus contorta and P. albicaulis do not interact with the main distribution of limber pine as these former trees cannot become established on the steep south exposures of Sentinel Ridge. Pinus flexilis does occur with P. albicaulis and P. contorta about the southeastern rim of the Sentinel Plateau where less steep south aspect and strong wind displacement of snow produce locally mesic sites. However, overall arboreal cover seldom exceeds 1% and the distribution of all three species appears to be limited by availability of microsites mesic enough to permit seedling establishment. Widespread restriction of Pinus flexilis by competition has been hypothesized by Lepper (1974) who further suggests the mode of restriction is the low growth rate of seedlings and saplings.

Within the Sentinel Meadow region Pinus contorta occurs on level or gently sloping terrain with west, north, or east aspect and above 2,700 m elevation. Stands occur on both rhyolite and obsidian substrate although best development occurs on the former. Three relatively distinct types of lodgepole pine stands have been identified within the Sentinel Ridge study area. These stand types represent varying degrees of suitability of environment for establishment, growth, and

dominance of Pinus contorta. In order of decreasing overall suitability for lodgepole pine these site types are: protected regions of plateaus or broad canyons, steep sloping sites on the north flank of Sentinel Ridge, and exposed upland plateau sites.

Protected plateau and broad canyon sites are sheltered from strong winds. They receive significant spring through fall solar beam irradiation but tree cover is sufficiently high (about 35%) to produce enough shade that development of a winter snow pack is assured in most years. Lack of wind-induced desiccation or direct physical damage to the crowns of trees is, thus, minimized while spring snow melt provides significant soil moisture at the time of shoot elongation and seedling establishment in spring. Results are forests of Pinus contorta whose height growth equals and diameter growth surpasses that of commercial stands in the Rocky Mountains (Fowells, 1965). Distribution of trees within this uneven aged forest is determined by density dependent "competitive" factors and, at infrequent intervals, fire.

The plateau on the eastern half of Sentinel Ridge is above 3,000 m elevation. While possessing essentially the same soil profile and energy inputs as the western "protected" plateau, wind effects are pronounced leading to reduced height growth after specimens are approximately 10 m tall. Strong winds also move snow from the southern to the northern side of the plateau. Resultant drought stress on the southern side of the plateau is sufficiently great to limit tree establishment of isolated

clusters of trees with less than 1% overall cover, resulting in open high elevation sites on gently sloping terrain which provide suitable habitat for numerous alpine and subalpine herb and shrub species. Within the northern half of the plateau moisture conditions are more favorable and an open lodgepole pine forest has developed. But even here the number and distribution of trees appears to be limited by moisture as wind blown snow accumulates in the shade about the bases of Pinus contorta and not in the openings between trees where presence of mineral soil would enhance seedling establishment.

North slope forests are largely confined to coarse soils derived from partially decomposed rhyolite where percolation is rapid and nutrient supplies probably limited. Pinus contorta height and diameter growth is less than for specimens within either protected or exposed plateau forests. However, the very cold winters (a consequence of low solar beam irradiation) permit development of a significant snow pack which releases moisture during spring. Resultant compensation for moisture permits mesic Sierra Nevada trees like Pinus albicaulis and P. monticola to maintain disjunct populations on this slope.

Forest Structure

Effects of climate upon establishment of Sentinel Ridge conifers can be estimated by comparing age class data with results of paleoclimatic chronologies derived from tree ring studies in the White Mountains 55 km to the southeast. The comparison of ring widths for White Mountain Pinus aristata growing about the drought sensitive lower forest border and

temperature sensitive upper tree line (LaMarche, 1974) is particularly useful as it suggests both temperature and moisture conditions for the past 1,150 years. This record reveals predominantly cold-moist climate from 1350 to 1500 A.D. At the beginning of the 14th Century climate warmed slightly only to become progressively cooler and drier throughout the remainder of the century. Cool conditions continued from 1600 to 1700, but deviations in precipitation may have been extreme with exceptionally moist climate between 1600 to 1620 and prolonged drought from 1620 to 1700. Temperatures warmed and then remained close to the thousand year mean between 1700 and 1860. Precipitation was variable with 1700 to 1780 relatively moist and pronounced drought between 1820 and 1860. After 1860 temperatures warmed, a trend which has continued into the present. There was also a sharp increase in precipitation about the turn of the century which has been followed by drought since the 1930's.

Comparison of these data with age class distributions in south slope Pinus jeffreyi forests reveal seedling establishment has been successful only during periods of moist climate: 1475 - 1525, 1575 - 1625, 1775 - 1825, and 1875 - 1925. Conversly gaps in the age distribution of Pinus jeffreyi correlate with periods of relative drought: 1425 - 1475, 1525 - 1575, 1625 - 1675, 1775 - 1825. Dependence of Pinus jeffreyi establishment upon a specific variation in climate would help explain the clustering of stand members into just a few age classes. Establishment during the warm-moist period between 1875 and 1925 was probably more extensive than during previous cold-moist

periods, as reproduction from this period has tended to fill gaps between clusters of very old trees and was the time of establishment for isolated Jeffrey pine now growing in the ridge crest sagebrush scrub. Reproduction from 1875 through 1925 is particularly abundant within Pinus jeffreyi stands on the eastern half of Sentinel Ridge's south flank where losses from the fire of 1858 were high. Restriction of successful establishment of Pinus jeffreyi to moist periods is probably a direct result of higher seedling water potentials during exceptionally moist years. This hypothesis is intuitive as Sentinel Meadow is near the eastern "xeric" boundary of Jeffrey pine's distribution.

Conversely, establishment in Pinus flexilis stands which are directly upslope from the Jeffrey pine forest, is positively correlated with periods of drought (1625 to 1725 and 1925 to the present), and may cease altogether during intervals of cool-moist or warm-moist climate. Gaps in establishment of Sentinel Ridge Pinus flexilis during periods of moist climate are unlikely to result from direct moisture related mortality of seedlings and saplings, as this tree grows best in well developed mesic soils (but is excluded from these sites by other conifers which grow even faster) (Lepper, 1974). A hypothesis for further study is that cool-moist climate interfers with some aspect of seed production. During fall 1977, after two years of extreme drought, limber pine were observed to possess abundant cones with viable seed.

Nearly uniform decline in the log frequency per age class of Pinus contorta at sheltered plateau sites is indicative of a

stable all-aged forest (Jackson and Faller, 1974), and implys there has been sufficient establishment to assure 100% stocking (at least over fifty year intervals) for the past 350 years. This condition occurs when large numbers of seedlings and saplings become established despite climatic and other environmental variables and subsequently engage in density dependent competition for the few open spaces in the canopy. The short life expectancy of Pinus contorta growing at sheltered plateau sites derives from their tall stature and greater cover. The former increases susceptibility to wind throw, while the latter increases opportunities for both insect and fire damage.

Pinus contorta establishment at exposed plateau sites has been uneven over time or gap phase. Peaks in the age class distribution occur between 1575 and 1625, and again between 1725 and 1825. Conversely, a gap in the P. contorta age class distribution occurs for trees which would have been established between 1625 and 1725. Both periods with peak establishment coincide with epochs of abnormally cool-moist climate while the large gap overlaps with a prolonged period of very cold-dry weather (LaMarche, 1974).

Successful establishment of north slope Pinus contorta is less sensitive to drought than specimens growing at exposed plateau sites. Peaks in the age class distribution within north slope forests are correlated with both cool-moist (1575-1625) and warm-moist (1875-1925) conditions with below average establishment occurring only during periods of extreme cold-dry climate (1625 to 1725) or the warm-dry conditions which have prevailed since the 1930's.

Age class distribution studies, thus, indicate water stress within lodgepole pine forests is greatest at exposed plateau sites and least on sheltered plateaus and within broad canyons. The mode of greater water stress at exposed sites is likely to be greater desiccation from wind. Wind-induced drought is reinforced by inhibition of seedling establishment since exposed plateau sites which possess abundant mineral soil, and are thus suitable for seedling estalbishment, also receive significant direct solar beam irradiation which generates a higher water need (Baer et al., 1977). Forests on the north facing slope of Sentinel Ridge are intermediate to exposed and sheltered plateau sites respecting moisture stress. North slope sites differ from both of these former types of sites in possessing a winter snow pack.

Fire

The widespread occurrence of fire on Sentinel Ridge about 1800 could represent unusual lightning activity during one or several closely spaced years. However, these fires also came when a dry period began after a half century of above average precipitation (LaMarche, 1974), and the possibility that herb stratum cover was sufficiently continuous at that time to carry a regional fire cannot be discounted. At present ground cover is extensive enough to carry a regional fire only within the sagebrush scrub, mountain mahogany woodland, and the lodgepole pine forest at sheltered plateau sites.

RECOMMENDATIONS

The region between Mono Craters and the northern White Mountains may be one of the lesser botanically explored areas of the state. Distributions of Pinus flexilis, P. albicaulis, P. monticola, P. monophylla, and Juniperus occidentalis ssp. australis in the Sentinel Ridge region were not know prior to 1975. An additional exploration effort equivalent to this report will be needed before we will actually know whether or not the botanical resources on Sentinel Ridge are unique. Particular effort should be made to compare the resources on Sentinel Ridge with those in the Indian Summit Natural Area to the west and Glass Mountain to the east.

Should a decision be made to reserve Sentinel Ridge as a Research Natural Area in the absence of botanical data relating this region to surrounding terrain, I suggest the eastern half of Sections 8 and 17 (mapped in Figure 1) be included with all of Sections 9 through 11 and 14 through 16. This recommendation is made to preserve a representative example of Populus tremuloides forest, and the ecotone between Pinus contorta forest and Jeffrey pine forest with the sagebrush scrub. While the latter community has been significantly disturbed, exclusion of domestic grazing animals from this region would, by itself, provide a valuable resource for future research.

Observation of Plant communities just outside the southern boundary of the proposed natural area further reveals unique clusters of Pinus jeffreyi about seepage springs where

surrounding vegetation is sagebrush scrub or pinyon-juniper woodland. Moreover, the stands of Juniperus occidentalis ssp australis (which are particularly well developed about the 2,400 m contour line in Sections 20, 21, and 22) appear to be very old. A reconnaissance study should be commissioned to determine if these stands are also of "natural area" caliber.

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Table 1. Temperature record for Bodie, California (1895-1906).

Month	Maximum (°C) Average	Maximum (°C) Highest Record	Minimum (°C) Average	Minimum (°C) Lowest Record
January	2.6	24.4	-14.2	-31.1
February	3.0	26.1	-13.0	-37.8
March	3.9	29.4	-11.7	-29.4
April	8.8	33.9	-7.5	-20.0
May	14.0	33.9	-4.1	-15.0
June	21.6	38.9	-0.6	-12.2
July	25.4	40.6	1.9	-9.4
August	24.1	42.8	0.8	-8.9
September	19.5	36.7	-2.9	-18.3
October	13.6	35.0	-7.2	-21.1
November	7.8	31.7	-9.7	-27.2
December	3.7	27.2	-13.7	-37.8
Average	12.3°C		-6.83°C	

Table 2. Dominant vegetation, slope, aspect, and elevation of study sites in Sentinel Meadow Candidate Research Natural Area.

Plot No.	Vegetation[1]	Slope (°)	Aspect (°)	Elevation (m)
3	At	14	185	2,932
31	At-Pj	13	190	2,911
43	At-Pj	11	90	2,991
34	At-Pj	9	180	2,847
35	Pj	7	210	2,829
6	Pj	32	125	2,926
7	Pj	31	110	2,707
39	Pj	35	110	2,707
37	Pj	31	215	2,725
36	Pj	29	100	2,709
38	Pj	31	170	2,731
33	Pj	29	170	2,877
44	Pj	30	160	2,975
4	Pj	25	230	2,865
5	Pj-Cl	22	145	2,950
16	Pf-Pj	19	170	3,024
32	Pf-Pj	29	170	2,957
13	Pf	19	185	2,999
19	Pf	22	220	2,998
14	Pf	23	115	3,072
28	Pa-Pc	21	290	3,018
25	Pa-Pf-Pc	25	260	3,048
18	Pa-Pf-Pc	16	45	3,024
15	Pa-Pc	14	40	3,060
29	Pa-Pc-Pm	32	285	2,883
23	Pc-Pa	23	95	3,024
24	Pc-Pa	16	5	3,054
26	Pc-Pa	17	310	3,060
10	Pc-Pf	14	220	2,963
27	Pc	8	195	3,027
21	Pc	3	140	3,078
12	Pc	21	275	2,972
22	Pc-Pa	13	110	3,048
17	Pc	10	40	2,896
20	Pc	8	280	2,926
9	Pc	13	45	2,950
8	Pc	5	90	2,908
1	Pc-Pt	0	Level	2,792

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[1] Abbreviations for dominant vegetation types are: At, *Artemisia tridentata*; Cl, *Cercocarpus ledifolius*; Pa, *Pinus albicaulis*; Pc, *Pinus contorta*; Pf, *Pinus flexilis*; Pj, *Pinus jeffrevi*; and Pm, *Pinus monticola*.

Table 3. A list of plant species within the vegetation cover types of the Sentinel Meadow Candidate Research Natural Area. "D" indicates a community dominant while "X" denotes principal occurrance of the species within the communities.

Plant Species	Community						
	Sagebrush scrub	Mountain Mahogany Woodland	Jeffrey Pine Forest	Limber Pine Forest	Subalpine Forest	Lodgepole Pine Forest	Lodgepole Pine-Whitebark Pine Forest
Artemisia tridentata	D	X	X				
Purshia tridentata	D	X	X				
Haplopappus suffruticosus	D	X	X	X			
Castilleja martinii	X	X	X	X			
Stephanomeria tenuifolia	X	X	X				
Silene montana ssp. bernardina	X	X	X				
Phlox stansburyi	X	X	X				
Eriogonum esmeraldense	X	X	X				
Erisimum argillosum	X	X	X				
Chaenactis douglasii var rubicaulis	X	X	X				
Lupinus alpestrus	X		X				
Orobanche corymbosa	X						
Eriastrum wilcoxii	X						
Tetradymia canescens	X						
Oryzopsis hymenoides	X						
Cercocarpus ledifolius	X	D	X	X			
Abronia turbinata		X					
Lygodesmia spinosa		X	X				
Juniperus occidentalis ssp. australis		X	X	X			
Pinus jeffreyi	X	X	D	X			
Chrysothamnus nauseosus ssp. albicaulis	X		X				
Eriophyllum lanatum var monoense			X	X	X		
Streptanthus tortuosus			X				
Cryptantha muricata var dentata			X				
Chrysothamnus viscidiflorus			X				
Eriogonum spergulinum var reddingianum			X				
Chrysolepis sempervirens			X				
Pinus flexilis				D	X		
Antennaria rosea				X			
Lesquerella kingii				X			
Monardella odoratissima				X			

Table 3. continued

	Sagebrush scrub	Mountain Mahogany Woodland	Jeffrey Pine Forest	Limber Pine Forest	Subalpine Forest	Lodgepole Pine Forest	Lodgepole Pine-Whitebark Pine Forest
Chambaebateria millefolium				X			
Machaeranthera shastensis var montana				X	X		
Ribes cereum	X				D		
Lupinus breweri				X	X	X	
Chrysothamnus viscidiflorus var pumilus					X		
Haplopappus macronema					X		
Phlox covillei					X		
Eriogonum ovalifolium var nivale					X		
Hulsea vestitata					X		
Raillardella argentea					X		
Senecio spartioides					X		
Cryptantha confertiflora					X		
Lupinus montigenus					X		
Mimulus coccineus					X		
Muhlenbergia richardsonia					X		
Calypteridium umbellatum				X	X	X	X
Pinus contorta ssp. murrayana					X	D	D
Carex sp.						X	X
Gayophytum nuttallii						X	X
Poa nervosa						X	X
Ribes roezlii						X	X
Lupinus alpestris						X	X
Chaenactis douglasii						X	X
Fransera puberulenta						X	X
Pterospora andromedea						X	
Populus tremuloides						X	
Angelica lineariloba						X	
Agoseris glauca var monticola						X	
Arenaria kingii						X	
Pinus albicaulis							D
Arabis holboellii							X
Arabis inyoensis							X
Eriogonum lobbii							X
Pinus monticola							X
Selaginella watsonii							X
Pellea breweri							X
Stipa elmeri	X	X	X			X	
Haplopappus suffruticosus	X	X	X	X	X	X	
Arabis platysperma	X	X	X	X	X	X	X

Table 3. continued

	Sagebrush scrub	Mountain Mahogany Woodland	Jeffrey Pine Forest	Limber Pine Forest	Subalpine Forest	Lodgepole Pine Forest	Lodgepole Pine-Whitebark Pine Forest
Symphoricarpos vaccinioides	X	X	X	X	X	X	
Lupinus arbustrus var calcoratus	X	X	X	X	X	X	
Linum perenne ssp. lewisii	X	X	X	X	X	X	
Gayophytum diffusum ssp. parviflorum	X	X	X	X	X	X	
Ipomopsis aggregata	X	X	X	X	X	X	
Leptodactylon pungens ssp. hallii	X	X	X	X	X	X	
Linanthus nutallii	X	X	X	X	X	X	
Eriogonum umbellatum var umbellatum	X	X	X	X	X	X	X
Sitanion hystrix	X	X	X	X	X	X	X
Holodiscus microphyllus	X	X	X	X	X	X	X
Penstemon speciosus	X	X	X	X	X	X	X

Table 4. Frequency, per cent cover, basal area, and Importance Value for arboreal species at Sentinel Meadow study sites. Values for Pinus monticola (plot 29), Cercocarpus ledifolius (plots 36, 16), and Populus tremuloides (plot 1) can be derived by subtraction from the total.

Plot No	Pinus jeffreyi				J. occidentalis				Pinus flexilis				Pinus albicaulis				Pinus contorta				TOTAL		
	Freq	%cov	BA	IV	Freq	%cov	BA	IV	Freq	%cov	BA	IV	Freq	%cov	BA	IV	Freq	%cov	BA	IV	Frequency	%cover	Basal Area
31	14	1	0.07	144													14	1	0.09	166	28	2	1.6
43	29	5	3.4	300																	29	5	3.4
34	72	6	3.3	300																	72	6	3.3
35	86	40	28	300																	86	40	28
6	100	40	40	300																	100	40	40
7	129	45	31	300																	129	45	31
39	100	55	44	300																	100	55	44
37	187	42	60	300																	187	42	60
36	115	34	46	194	14	1	0.6	7													344	50	49
38	57	40	32	300																	57	40	32
33	258	55	36	300																	258	55	36
44	187	46	44	300																	187	46	44
4	100	63	65	300																	100	63	65
5	43	18	20	127																	757	35.5	29.3
16	57	3	2.3	130					72	1	0.1	52									201	6.5	3.9
32	14	1	0.7	56					72	1	3.01	136									143	3	5.7
13					186	5	15	145	114	10	15	155									300	15	30
19									290	15	17	300									290	15	17
14									200	10	12	123	352	20	11	177					552	30	23
25									14	2.5	1.5	106	29	3.5	1.9	158	14	0.5	0.1	36	57	6.5	3.5
28									14	5	0.1	33	458	10	8.5	193	72	0.5	11	73	544	16	53
18									29	7	8.0	83	14	21	208	222	72	18	14	55	115	42	245
15													672	29	21.6	206	186	5.5	27	94	858	35	49
29													415	9	4.2	117	114	10	11	131	558	25	21
23													157	7.5	5.2	89	200	23	20	211	357	31	25
24													143	5.5	4.4	57	315	30	45	243	458	36	50
26													186	9	2.9	61	558	26	25	239	744	34	28
10									14	30	4.1	105					114	5.5	38	195	128	36	42
27																	100	10	17	300	100	10	17
21																	57	30	13	300	57	30	13
12																	172	15	18	300	172	15	18
22																	243	29	18	290	257	30	28
17													14	1	0.2	10	114	35	17	300	114	35	17
20																	172	55	29	300	172	55	29
9																	186	35	24	300	186	35	24
8																	486	45	36	300	486	45	36
1																	243	43	39	248	257	48	39

[1] Juniperus occidentalis.

[2] Abbreviations: freq = frequency in stems/ha; %cov = Percent cover; BA = basal area in m^2/ha; IV = importance value.

Table 5. Age of conifers at breast height (1.4 meters).

Pinus flexilis

Plot No.	Age (yrs)
18	56

Pinus contorta

Plot No.	Age (yrs)
16	36
	47
17	57
	62
	62
18	41
21	22
22	40
	38
23	49
	61
24	87
26	80
28	39
29	48
	51
	48

51.4 ± 16.1 yrs

Pinus jeffreyi

Plot No.	Age (yrs)
34	19
36	25
39	22
43	30
44	32

25.6 ± 5.4 yrs

Pinus albicaulis

Plot No.	Age (yrs)
14	47
	50
16	31
	38
18	42
	62
22	42
23	59
24	41
28	49

47.6 ± 10.1 yrs

Table 6. Suggested age-diameter classes for *Pinus albicaulis*, *P. flexilis* and *P. contorta* at Sentinel Meadow Candidate Research Natural Area.

Age Class	*P. albicaulis*	*P. flexilis*	*P. contorta*	
			Sheltered Plateau Site[1]	Exposed Plateau and N. Slopes[2]
0-50 yrs	0-1.4 m ht	0-1.4 m ht	0-1.4 m ht	0-1.4 m ht
51-100	0-6 cm dbh	0-12 cm dbh	0-22 cm dbh	0-22 cm dbh
101-150	6-13	12-31	22-43	22-30
151-200	13-21	31-48	43-68	30-37
201-250	21-28	48-61	68-71	37-44
251-300	28-37	61-71	71-82	44-50
301-350	37-44	71-81	82-93	50-56
351-400	44-50	81-91	93-104*[3]	56-62*
401-450	50-56*	91-100*	----	62-68*
451-500	56-62*	100-110*	----	68-74*

[1] Sheltered plateau sites include plots 8, 9, 17, and 20.

[2] Exposed plateau sites include plots 1, 10, 15, 18, 21, 22, 23, 26, 27.
North slope sites are plots 24, 25, 26, 28 and 29.

[3] Asterisks indicate estimates of diameter for a given age-class based upon the previous nature of the age-diameter relationship.

Table 7. Approximate dates of fires at three selected Jeffrey pine and lodgepole pine sites within the proposed Sentinel Meadow Research Natural Area. ("X" indicates a fire).

Approximate Date of Fire	Jeffrey Pine Forest			Lodgepole Pine Forest		
	Plot 37	Plot 39	Plot 44	Plot 26	Plot 27	Plot 40
1907		X				
1880		X				
1869		X				
1864		X				X
1858	X	X	X			
1845				X		
1800	X	X	X		X	X

Table 8. Potential Solar Beam Irradiation of Typical Slope-Aspect Combinations for Sentinel Meadow Forest and Scrub Cover Types.[1]

Potential Solar Beam Irradiation by Cover Type				
Cover Type	Pinus jeffreyi		Cercocarpus ledifolius Pinus jeffreyi	Artemisia tridentata Pinus jeffreyi
Aspect	SW-SE	S	SSW	SW-SE
Slope %	50%	60%	50%	20%
June 22[2]	948 Ly/day	877	922	1003
May 3, Aug 10	932	905	929	946
Mar 31, Sept 23	850	910	887	792
Feb 7, Nov 5	699	833	769	590
Dec 22	599	754	680	473
Total[3]	297	316	309	281
RI[4]	0.57	0.60	0.59	0.53

Cover Type	Pinus flexilis		Pinus flexilis Pinus albicaulis	Pinus flexilis Pinus contorta	
Aspect	SW-SE	S	E-W	SW-SE	NW-NE
Slope %	40%	40%	40%	20%	30%
June 22	969	943	986	1003	993
May 3, Aug 10	941	938	904	946	860
Mar 31, Sept 23	837	881	712	792	592
Feb 7, Nov 5	670	751	487	590	264
Dec 22	564	656	366	473	199
Total	294	308	255	281	219
RI	0.56	0.59	0.49	0.53	0.42

Table 8. continued.

Cover Type	Pinus contorta				
Aspect	Level	N	NW-NE	W-E	S
Slope %	0%	10%	20%	30%	10%
June 22	1021	1014	1011	1000	1011
May 3, Aug 10	930	877	890	915	944
Mar 31, Sept 23	723	598	637	716	775
Feb 7, Nov 5	485	320	374	487	563
Dec 22	359	191	246	364	444
Total	260	221	233	257	276
RI	0.49	0.42	0.44	0.49	0.53

Cover Type	Pinus albicaulis P. contorta		Pinus contorta, P. albicaulis P. monticola
Aspect	NNW-NNE	N	NW-NE
Slope	40%	30%	60%
June 22	970	996	910
May 3, Aug 10	802	840	758
Mar 31, Sept 23	486	530	473
Feb 7, Nov 5	141	178	215
Dec 22	82	116	106
Total	187	201	181
RI	0.36	0.38	0.34

[1] Data derived from Frank and Lee (1966) using tables for 38° N Latitude.

[2] Potential solar beam irradiation in Langleys per day for representative dates listed.

[3] Total potential solar beam irradiation per year in thousands of Langleys.

[4] RI = Radiation Index, the percent of potential sunlight striking a unit surface in one year.

Figure Captions

Figure 1. The Sentinel Meadow Candidate Research Natural Area showing topographic gradients and the distribution of vegetation cover types. Numbered points represent the locations of 0.07 ha study sites. Letters stand for scientific names of dominant species: At, *Artemisia tridentata*; Cl, *Cercocarpus ledifolius*; Pa, *Pinus albicaulis*; Pc, *Pinus contorta*; Pf, *Pinus flexilis*; Pj, *Pinus jeffreyi*; Pm, *Pinus monophylla*; Pt, *Populus tremuloides*; Rc, *Ribes cereum*; X, areas where scattered specimens of *Pinus monticola* occur.

Figure 2. Age-diameter relationship for *Pinus jeffreyi*. Diameters and ages were measured at breast height (1.4 m). Numbers indicate plots from which trees were sampled.

Figure 3. Age-diameter relationship for *Pinus contorta*. Diameters and ages were measured at breast height (1.4 m). Dashed line represents the proposed age-diameter relationship for protected and exposed plateau sites while the solid line represents trees growing on the steep north flank of Sentinel Ridge. Numbers indicate from which plots trees were sampled.

Figure 4. Age-diameter relationship for *Pinus albicaulis*. Diameters and ages were measured at breast height (1.4 m). Numbers indicate plots from which trees were sampled.

Figure 5. Age-diameter relationship for *Pinus flexilis*. Diameters and ages were measured at breast height (1.4 m). Numbers indicate plots from which trees were sampled.

Figure 6. Age-height relationship for *Pinus jeffreyi*. Ages of trees were taken from 1.4 m above the base. Numbers indicate plots from which trees were sampled.

Figure 7. Age-height relationship for *Pinus contorta* and *Pinus albicaulis*. Separate relationships are indicated for both species based upon degree of exposure. Ages of trees were taken from 1.4 m above the base. Numbers indicate plots from which trees were sampled.

Figure 8. Age-height relationships for Pinus flexilis (solid line) and Pinus monticola (dashed line). Ages of trees were taken from 1.4 m above the base. Numbers indicate plots from which trees were sampled.

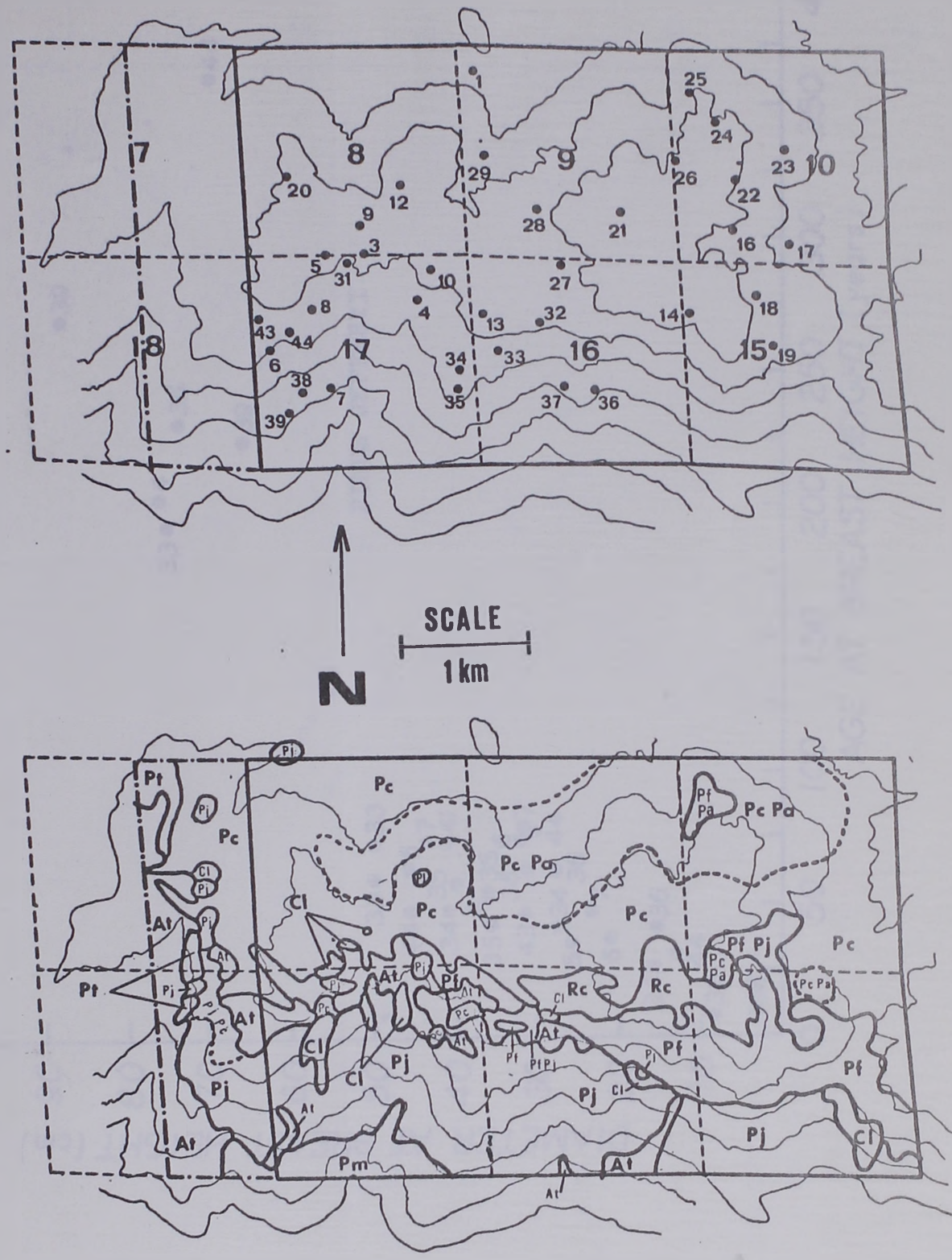
Figure 9. Survivorship curve for Pinus jeffreyi within the Sentinel Meadow study area. Age classes were determined by coring selected trees in each size class at each study site and extrapolating these results to the remainder of trees at the plot.

Figure 10. Survivorship curve for Pinus flexilis within the Sentinel Meadow study area. Diameters for various age classes are given in Table 6.

Figure 11. Survivorship curve for all Pinus contorta sampled within the Sentinel Meadow study area (solid line) and Pinus contorta at sheltered plateau sites (dashed line). Diameter for age classes are given in Table 6.

Figure 12. Survivorship curve for Pinus contorta growing on exposed plateau (dashed line) and north facing slopes (solid line) within the Sentinel Meadow study area. Diameters for age classes are given in Table 6.

Figure 1


7
8
9
10
18
17
16
15
1
25
24
23
29
26
22
20
12
9
28
21
16
17
3
5
31
10
27
8
4
13
32
14
18
43
44
6
34
33
19
38
7
35
37
36
39
SCALE
1 km
N
Pf
Pi
Pc
Cl
At
Pc Pa
Pf Pj
Rc
Pj
Pm

DIAMETER AT BREAST HEIGHT (cm)
AGE AT BREAST HEIGHT (years)
PINUS JEFFREYI
110
100
90
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
400
38
39
33 4 36
44
39
6
33 33
44 6 7
34 35 41
35 4 35 6
36
43 7
34 44
5 36
7
6
34 36
44
35
36

Figure 2

Figure 3

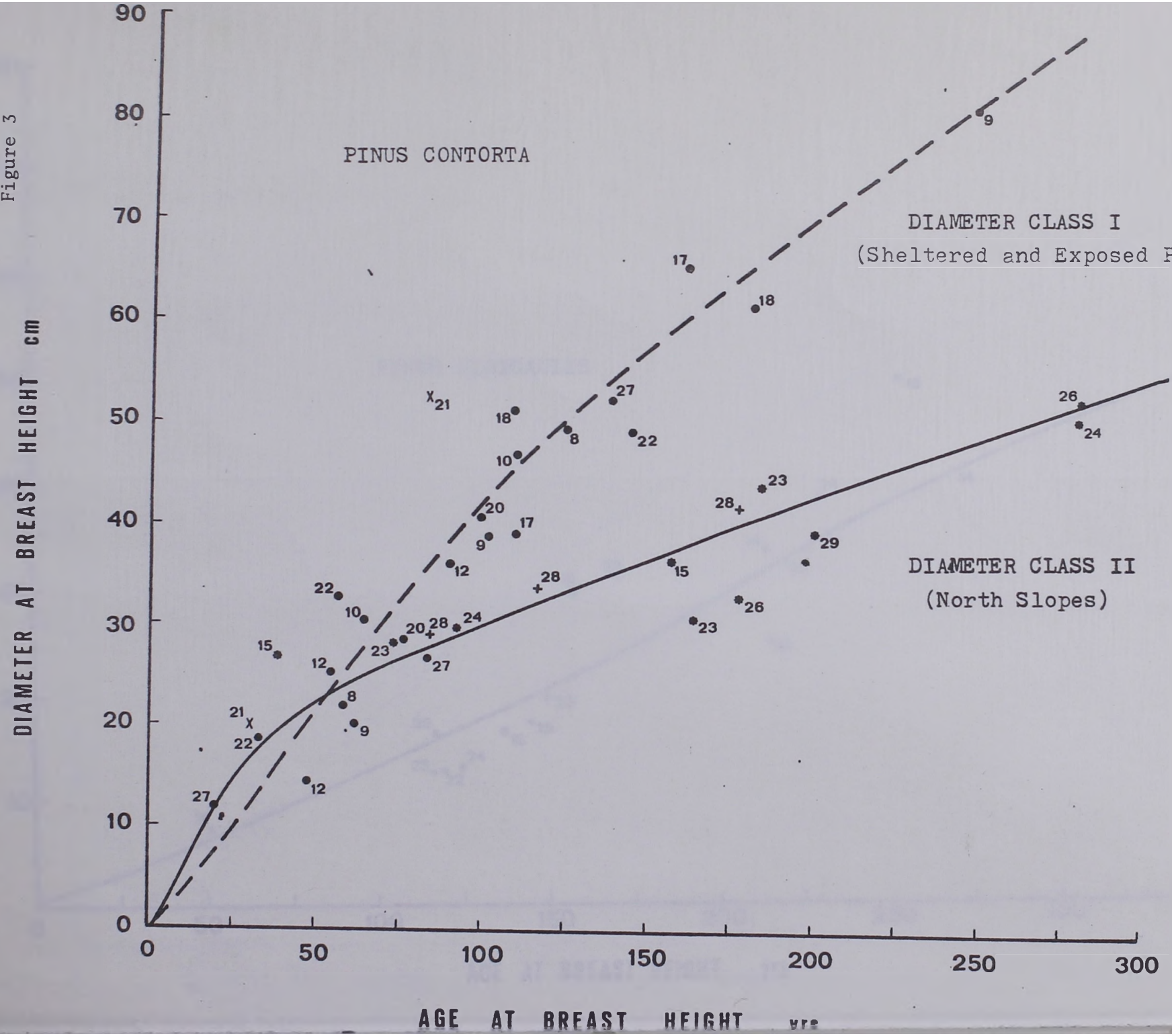

PINUS CONTORTA
DIAMETER CLASS I
(Sheltered and Exposed Plateaus)
DIAMETER CLASS II
(North Slopes)
DIAMETER AT BREAST HEIGHT cm
AGE AT BREAST HEIGHT yrs
0
10
20
30
40
50
60
70
80
90
0
50
100
150
200
250
300

Figure 4

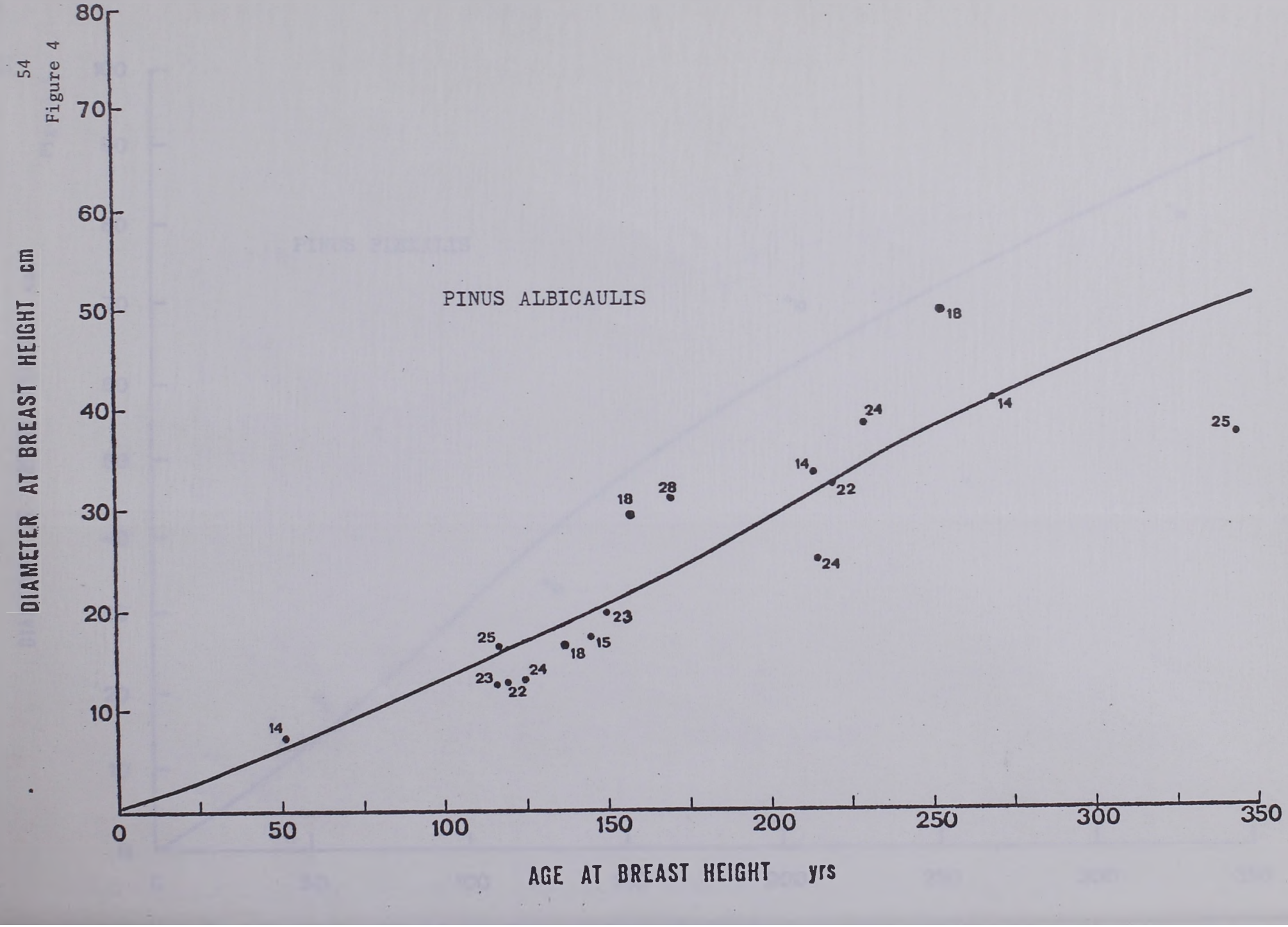

PINUS ALBICAULIS
DIAMETER AT BREAST HEIGHT cm
AGE AT BREAST HEIGHT yrs
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
350
14
25
23
22
24
18
15
23
18
28
24
14
22
24
18
14
25

Figure 5

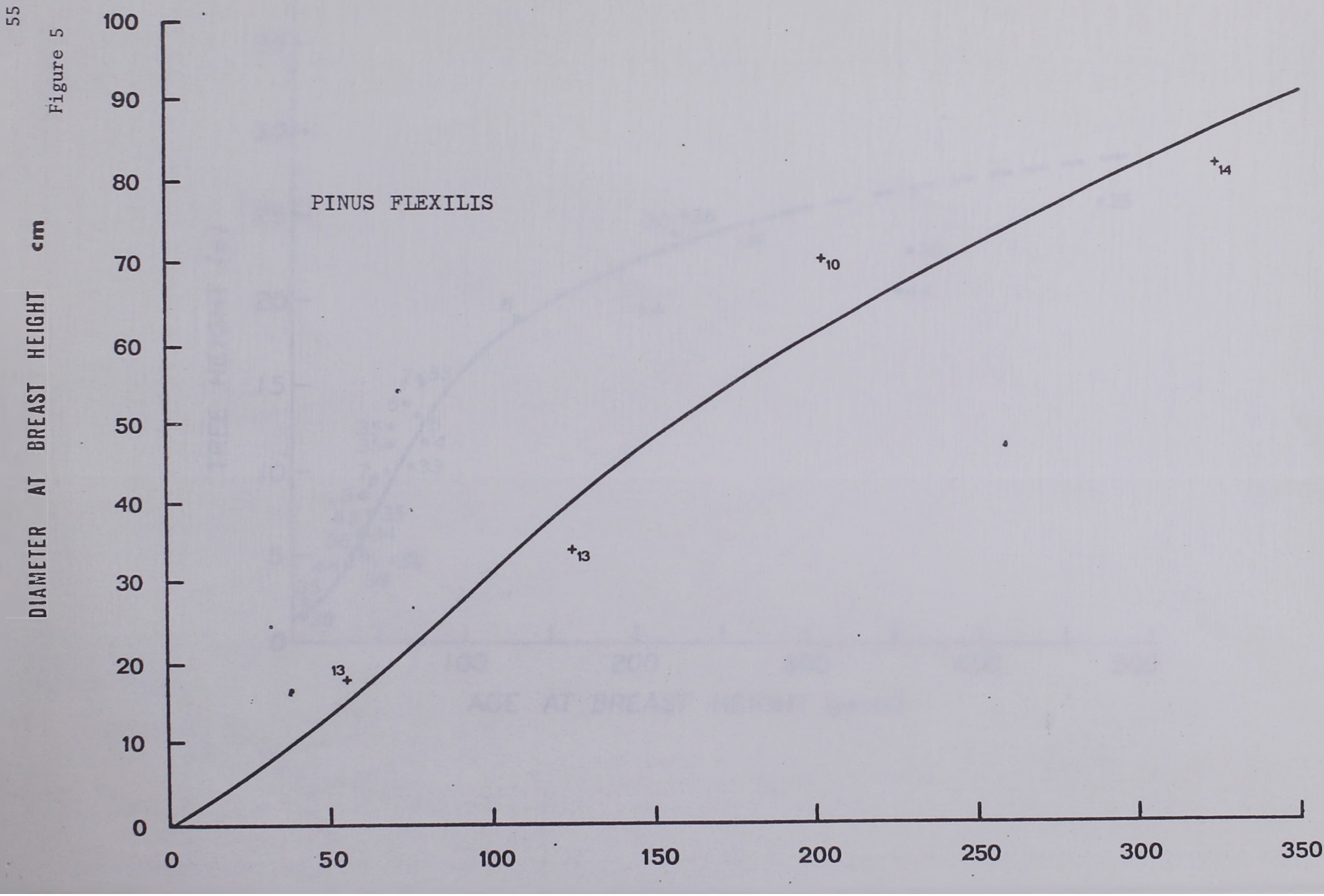
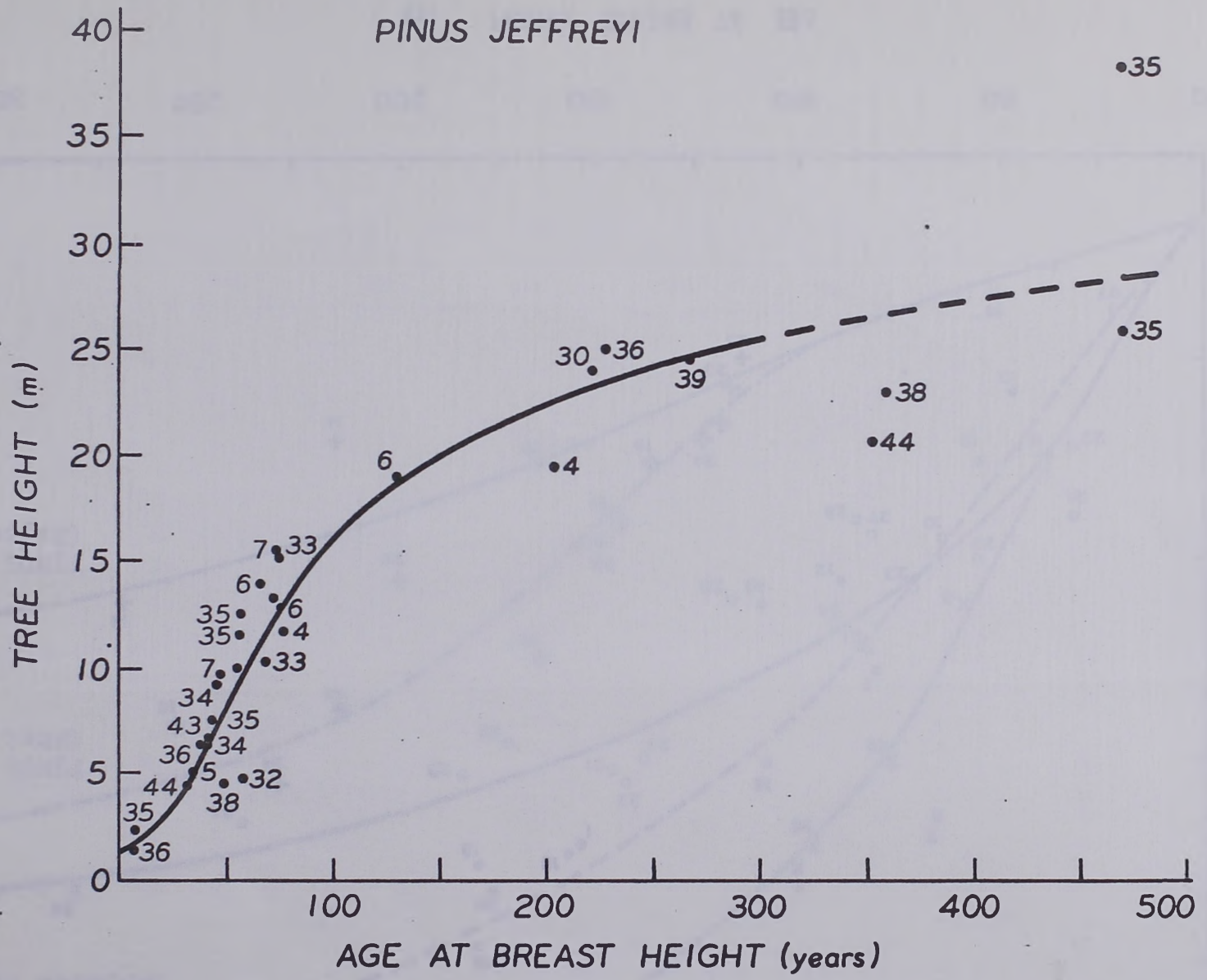

PINUS FLEXILIS
DIAMETER AT BREAST HEIGHT cm
AGE AT BREAST HEIGHT
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300
350
13
13
10
14

Figure 6


PINUS JEFFREYI
TREE HEIGHT (m)
AGE AT BREAST HEIGHT (years)
0
5
10
15
20
25
30
35
40
100
200
300
400
500

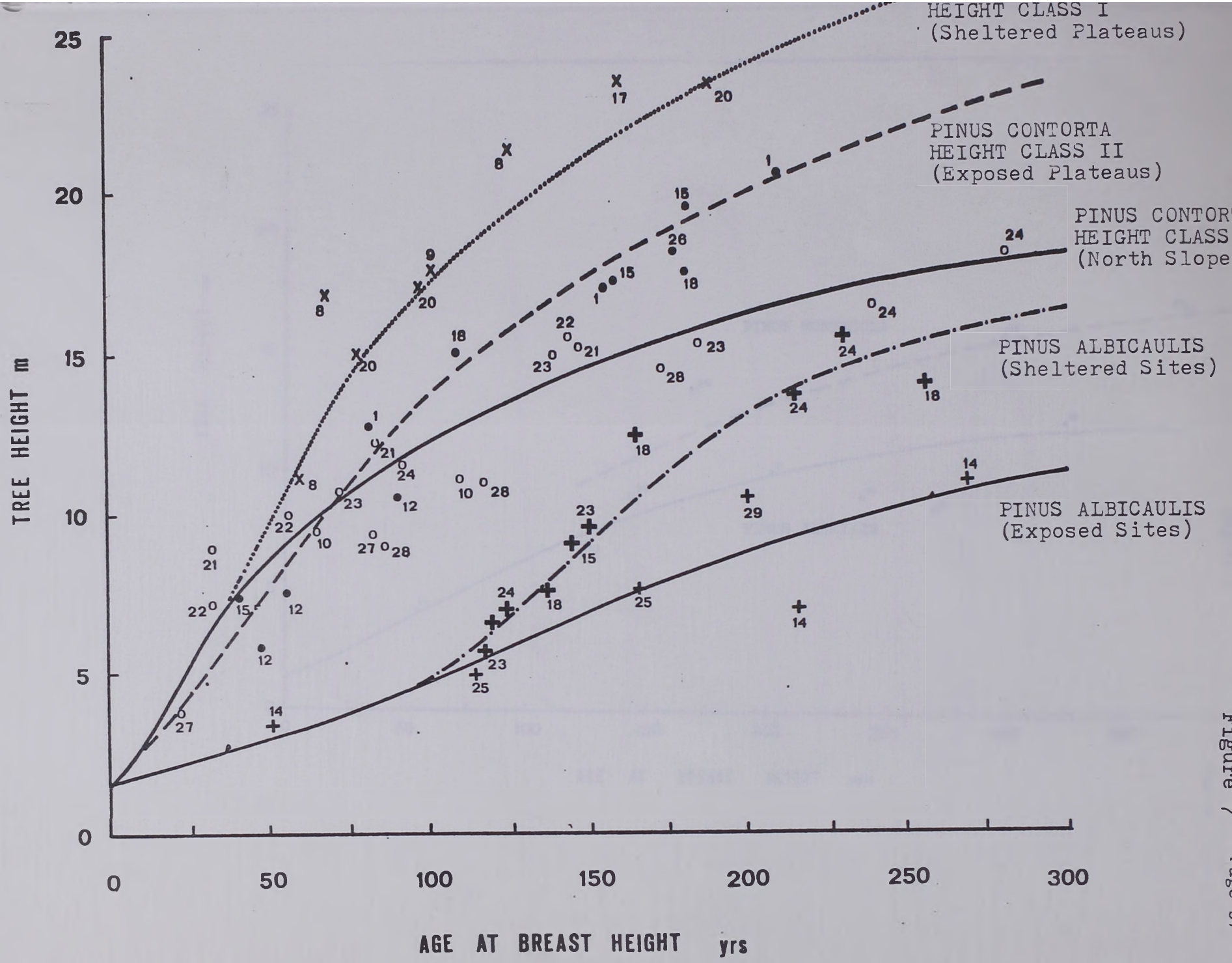

PINUS CONTORTA
HEIGHT CLASS I
(Sheltered Plateaus)
PINUS CONTORTA
HEIGHT CLASS II
(Exposed Plateaus)
PINUS CONTORTA
HEIGHT CLASS I
(North Slopes)
PINUS ALBICAULIS
(Sheltered Sites)
PINUS ALBICAULIS
(Exposed Sites)
TREE HEIGHT m
AGE AT BREAST HEIGHT yrs
0
5
10
15
20
25
0
50
100
150
200
250
300

Figure 7

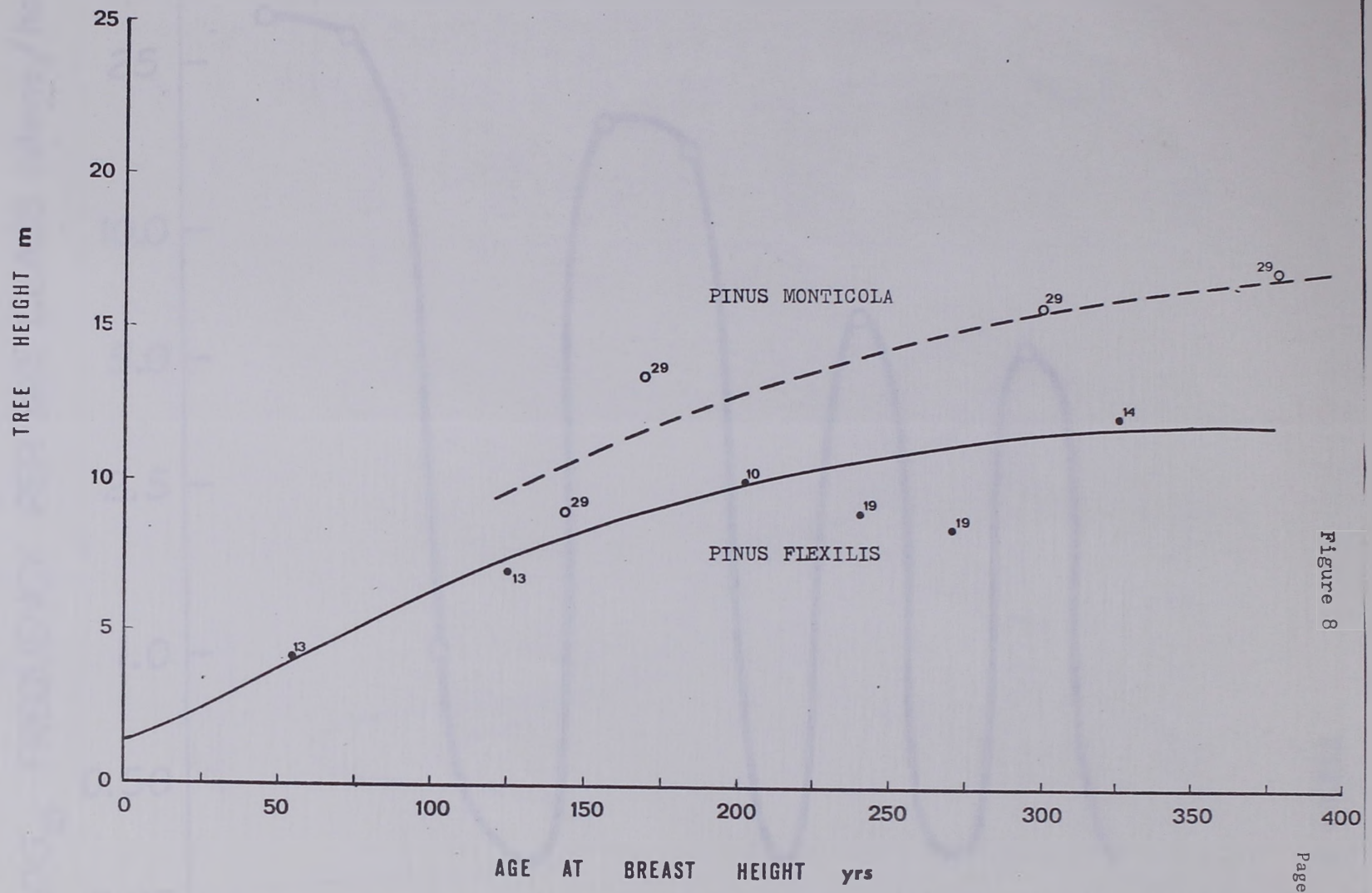

TREE HEIGHT m
25
20
15
10
5
0
0
50
100
150
200
250
300
350
400
AGE AT BREAST HEIGHT yrs
PINUS MONTICOLA
PINUS FLEXILIS
29
29
29
14
10
19
19
13
13

Figure 8

Figure 9

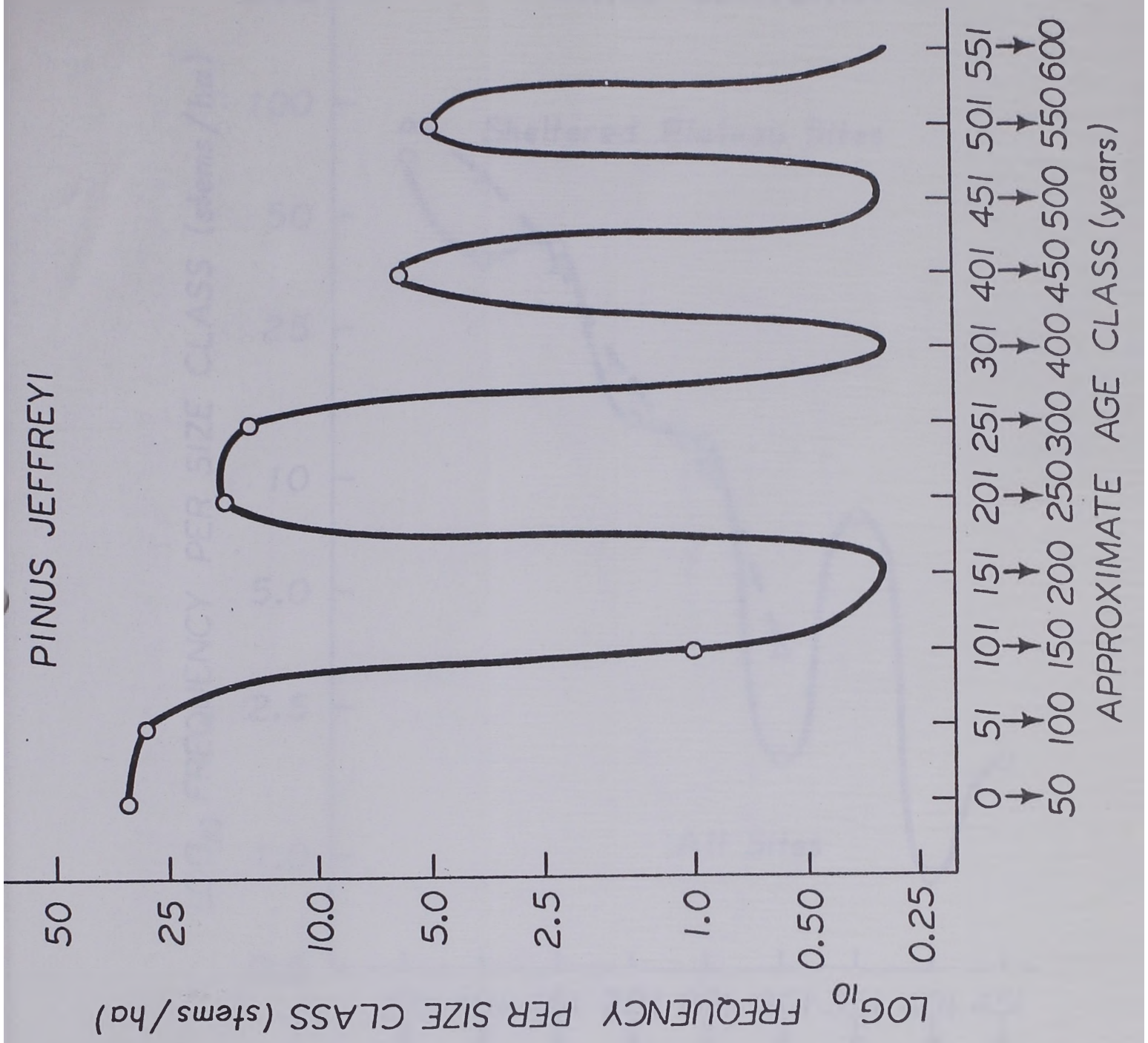

PINUS JEFFREYI
LOG10 FREQUENCY PER SIZE CLASS (stems/ha)
50
25
10.0
5.0
2.5
1.0
0.50
0.25
0 → 50
51 → 100
101 → 150
151 → 200
201 → 250
251 → 300
301 → 400
401 → 450
451 → 500
501 → 550
551 → 600
APPROXIMATE AGE CLASS (years)

Figure 10

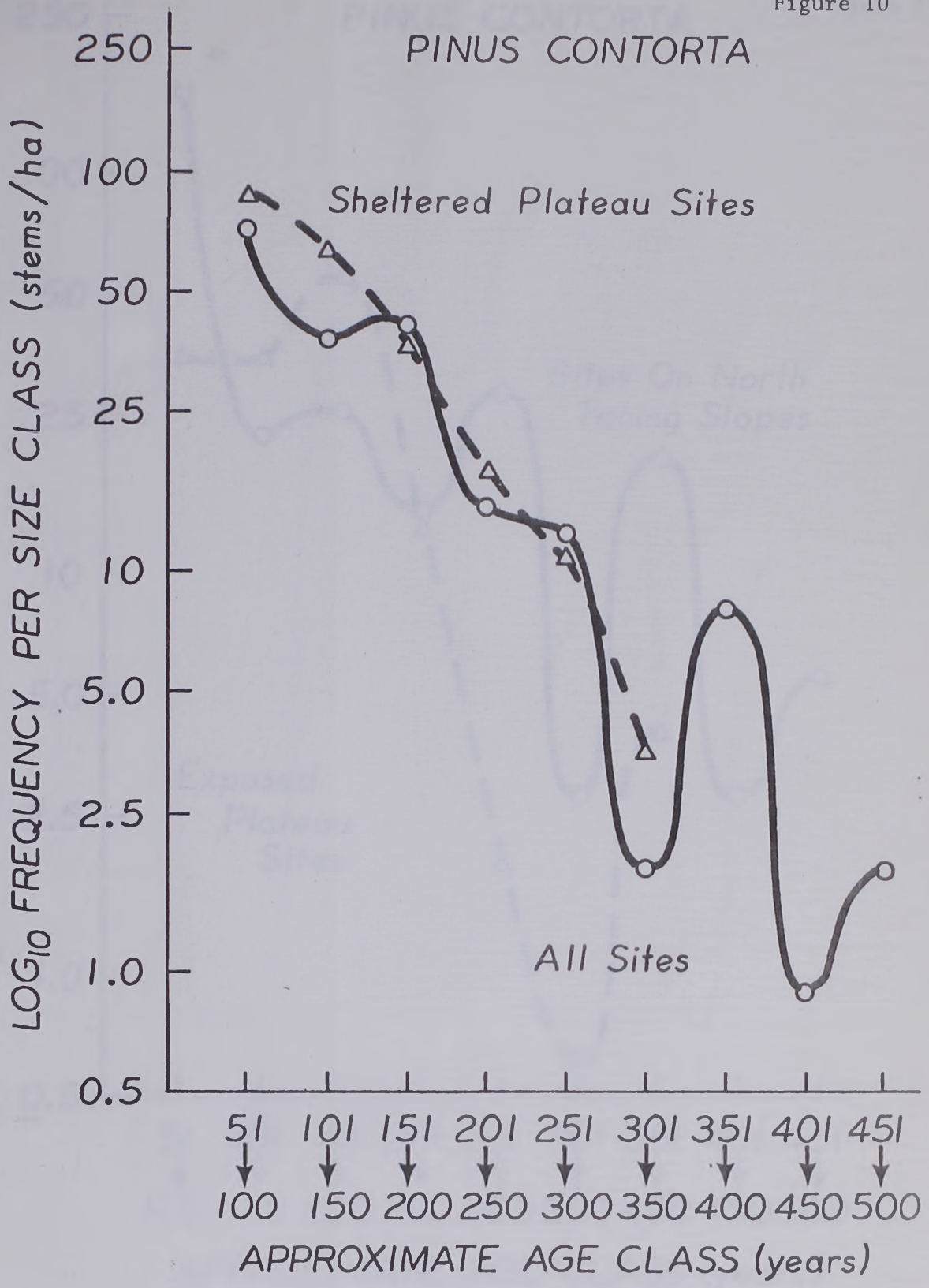
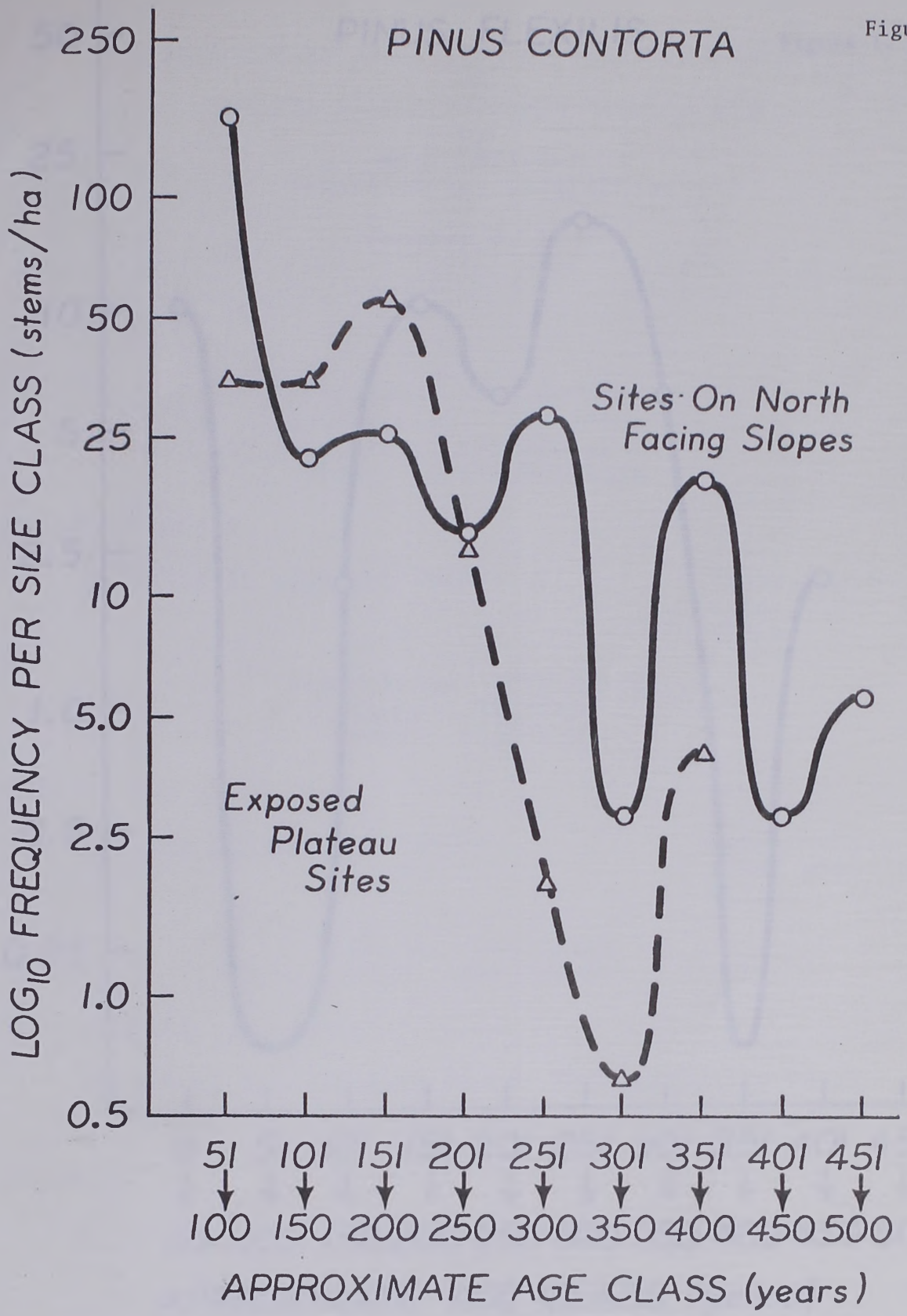

PINUS CONTORTA
Sheltered Plateau Sites
All Sites
250
100
50
25
10
5.0
2.5
1.0
0.5
LOG10 FREQUENCY PER SIZE CLASS (stems/ha)
51 101 151 201 251 301 351 401 451
100 150 200 250 300 350 400 450 500
APPROXIMATE AGE CLASS (years)

Figure 11


PINUS CONTORTA
250
100
50
25
10
5.0
2.5
1.0
0.5
LOG10 FREQUENCY PER SIZE CLASS (stems/ha)
Sites On North Facing Slopes
Exposed Plateau Sites
51 101 151 201 251 301 351 401 451
100 150 200 250 300 350 400 450 500
APPROXIMATE AGE CLASS (years)

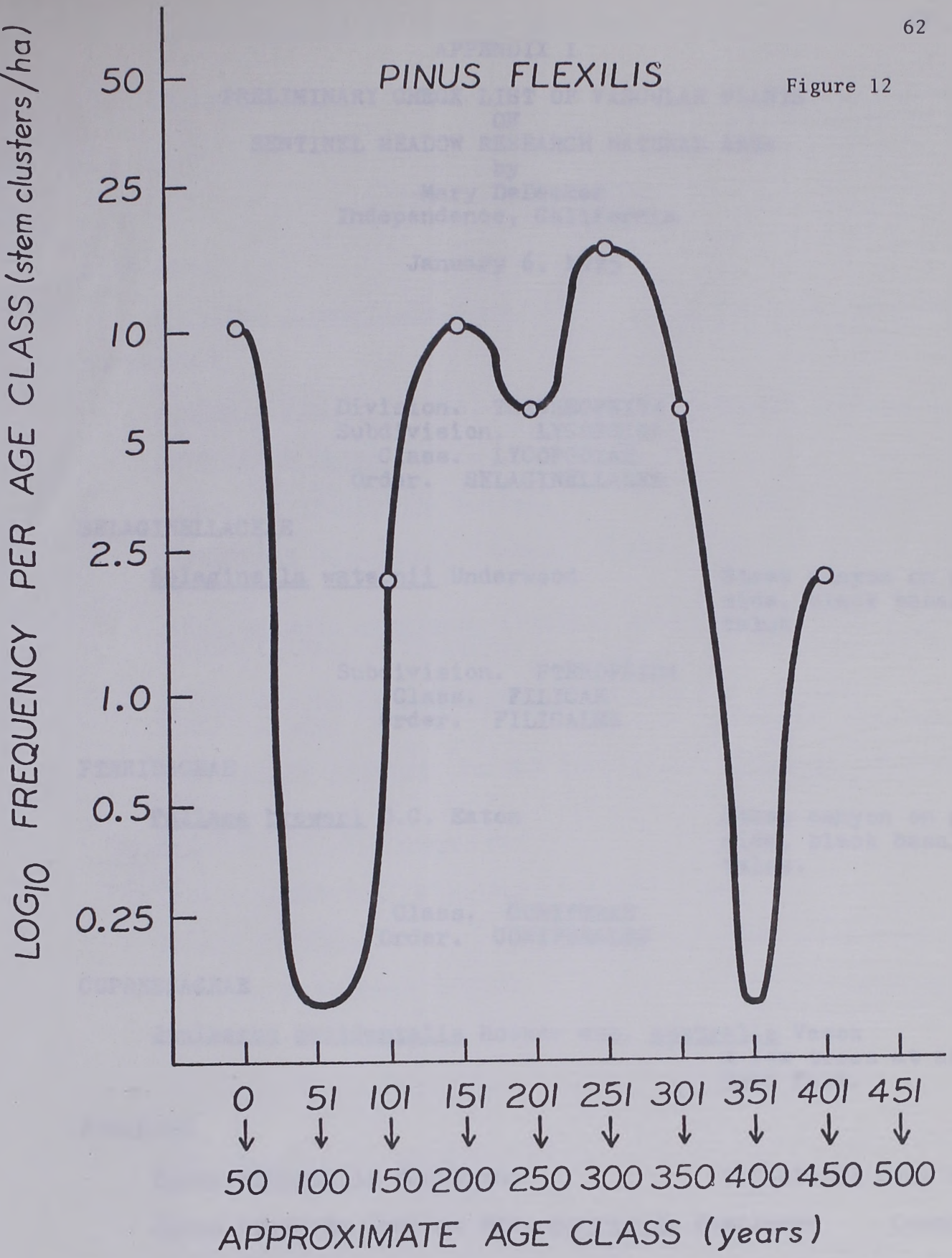

PINUS FLEXILIS
LOG10 FREQUENCY PER AGE CLASS (stem clusters/ha)
50
25
10
5
2.5
1.0
0.5
0.25
0 51 101 151 201 251 301 351 401 451
50 100 150 200 250 300 350 400 450 500
APPROXIMATE AGE CLASS (years)

Figure 12

APPENDIX I

PRELIMINARY CHECK LIST OF VASCULAR PLANTS OF SENTINEL MEADOW RESEARCH NATURAL AREA

by
Mary DeDecker
Independence, California

January 6, 1975

Division. TRACHEOPHYTA
Subdivision. LYCOPSIDA
Class. LYCOPODIAE
Order. SELAGINELLALES

SELAGINELLACEAE

Selaginella watsonii Underwood	Steep canyon on north side, black basalt talus

Subdivision. PTEROPSIDA
Class. FILICAE
Order. FILICALES

PTERIDACEAE

Pellaea breweri D.C. Eaton	Steep canyon on north side, black basalt talus.

Class. CONIFERAE
Order. CONIFERALES

CUPRESSACEAE

Juniperus occidentalis Hooker ssp. australis Vasek	A few trees at about 9000 feet.

PINACEAE

Pinus albicaulis Engelmann	Occasional near summit.
Pinus contorta Douglas var. murrayana Engelmann	Common.
Pinus flexilis James	Frequent along edge and summit of ridge.

Pinus jeffreyi Greville & Balfour	Occasional, lower slopes.
Pinus monticola Douglas	Five trees found in steep canyon on north side.

Class. ANGIOSPERMAE
Subclass. DICOTYLEDONES

APIACEAE

Angelica lineariloba Gray	West end of plateau.

ASTERACEAE

Agoseris glauca (Pursh) Greene var. Monticola (Greene)Q. Jones	
Antennaria rosea Greene	
Artemisia tridentata Nuttall	Lower borders.
Chaenactis douglassii (Hooker) Hooker & Arnott var. rubricaulis (Rydberg) Ferris	
Chrysothamnus nauseosus (Pallas) Britton ssp. albicaulis (Nuttall) Hall & Clements	Lower edge of forest.
Chrysothamnus viscidiflorus (Hooker) Nuttall ssp. viscidiflorus	Pumilus form on summit.
Eriophyllum lanatum (Pursh) Forbes var. monoense (Rydberg) Jepson	
Haploppapus macronema Gray	
Happlopappus suffruticosus (Nuttall) Gray	
Hulsea vestita Gray	Open area near summit.
Lygodesmia spinosa Nuttall	With Cercocarpus in open places on south edge.
Machaeranthera shastensis Gray var. Montana (Greene) Cronquist & Keck	
Raillardella argentea A. Gray	Small colonies on summit slope, open places.
Senecio spartioides Torrey & Gray	Near summit.
Stephanomeria tenuifolia (Torrey) Hall	Lower slopes.

Tetradymia canescens Decandolle — Occasional.

BORAGINACEAE

Cryptantha confertiflora (Greene) Payson — Near summit.

Cryptantha muricata (Hooker & Arnott) Nelson & Macbride var. denticulata (Greene) Johnston

BRASSICACEAE

Arabis holboellii Hornemann var. pinetorum (Tidestrom) Rollins — North slope.

Arabis inyoensis Rollins — Occasional.

Arabis platysperma Gray

Erysimum argillosum (Greene) Rydberg

Lesquerella kingii Watson ssp. kingii — Near summit with Pinus flexilis.

CAPRIFOLIACEAE

Symphoricarpos vaccinoides Rydberh

CARYOPHYLLACEAE

Arenaria kingii (Watson) Jones var. glabrescens (Watson) Maguire

Silene bernardina Watson ssp. maguirei Bocquet

ERICACEAE

Pterospora andromedea Nuttall — One site on north side.

GENTIANACEAE

Frasera puberulenta A. Davidson

LAMIACEAE

Monardella odoratissima Bentham ssp. parviflora (Greene) Epling — On black obsidian talus.

FABACEAE

Lupinus alpestris A. Nelson

Lupinus arbustus Douglas ex Lindley ssp. calcaratus (Kellogg) D. Dunn

Lupinus breweri Gray var. grandiflorus C. P. Smith — Open places on summit.

Lupinus montigenus Heller — Open area near summit.

LINACEAE

Linum lewissii Pursh — Edge of forest, west end.

NYCTAGINACEAE

Abronia turbinata Torrey — With Cercocarpus in open places, south edge.

ONAGRACEAE

Gayophytum diffusum Torrey & Gran ssp. parviflorum Lewis & Szweykowski

OROBANCHACEAE

Orobanche corymbosa (Rydberg) Ferris — With Artemisia.

POLEMONIACEAE

Eriastrum wilcoxii (A. Nelson) Mason

Ipomopsis aggregata (Pursh) V. Grant (toward ssp. arizonica) — Lower edge of forest.

Leptodactylon pungens (Torrey) Rydberg ssp. hallii (Parish) Mason

Linanthus nuttallii (Gray) Greene ex Milliken

Phlox covillei E. Nelson — Occasional, near summit.

Phlox stansburyi (Torrey) Heller var. brevifolia (Gray) Nelson

POLYGONACEAE

Eriogonum esmeraldense Watson — One colony, near west end.

Eriogonum lobbii Torrey & Gray — North side near summit.

Eriogonum ovalifolium Nuttall var. nivale (Canby) Jones — Occasional, open summit.

Eriogonum spergulinum Gray var. reddingianum (Jones) J.T. Howell

Eriogonum umbellatum Torrey var. *umbellatum* With *Artemisia*.

PORTULACACEAE

Calyptridium umbellatum (Torrey) Greene var. *caudiciferum* (Gray) Jepson

ROSACEAE

Cercocarpus ledifolius Nuttall — Along south edge of ridge, bordering summit slope.

Holodiscus microphyllus Rydberg

Purshia tridentata (Pursh) Decandolle

SALICACEAE

Populus tremuloides Michaux — Near base of north slope.

SAXIFRAGACEAE

Ribes cereum Douglas — Well developed on summit.

SCROPHULARIACEAE

Castilleja martinii Abrams var. *clokeyi* (Pennell) N. Holmgren

Mimulus coccineus Congdon — A few colonies near summit.

Penstemon speciosus Douglas

Subclass. MONOCOTYLEDONES

POACEAE

Muhlenbergia richardsonis (Trinius) Rydberg — High open places.

Oryzopsis hymenoides (Roemer & Schultes) Ricker — Occasionaal.

Poa nervosa (Hooker) Vasey — Forest slopes.

Sitanion hystrix (Nuttall) J.G. Smith

Stipa elmeri Piper & Brodie ex Scribner — Forest edge.